AD NUMBER	
AD397989	
CLASSIFICATION CHANGES	
TO:	**unclassified**
FROM:	**restricted**
LIMITATION CHANGES	
TO: **Approved for public release; distribution is unlimited.**	
FROM: **Distribution authorized to DoD only; Foreign Government Information; JUL 1967. Other requests shall be referred to British Embassy, 3100 Massachusetts Avenue, NW, Washington, DC 20008.**	
AUTHORITY	
DSTL ltr dtd 15 Feb 2009; DSTL ltr dtd 15 Feb 2009	

JOURNAL
OF THE
ROYAL NAVAL SCIENTIFIC SERVICE

Vol. 22 ★ JULY 1967 ★ No. 4

RESTRICTED

Decl OADR

Journal of the ROYAL NAVAL SCIENTIFIC SERVICE

Vol. 22, No. 4 JULY, 1967

CONTENTS

[redacted]D.

THE MILITARY ENGINEERING EXPERIMENTAL ESTABLISHMENT

R. A. Foulkes, M.A., M.I.C.E., M.N.E.C.Inst.E.& S.
Director

Introduction

MEXE occupies the site of the Barracks in Christchurch originally built during the Napoleonic Wars. The soldiers were then also used to suppress smuggling, though there is some doubt about which side they supported. Now all that remains of the Barracks is the Guard Room, preserved for historical reasons.

The origin of MEXE is to be found in World War I, when an Experimental Bridging Company was set up on the River Stour adjacent to the Barracks, and this later, in 1919, became the Experimental Bridging Establishment. When the Ministry of Supply was formed it was transferred to that Ministry and at the end of World War II its functions were enlarged and its name changed to the Military Engineering Experimental Establishment. Later when the M.O.S. dissolved MEXE reverted to the Army Department of the Ministry of Defence.

The present responsibility of MEXE is the design, development and testing of a wide range of equipment used by the Royal Engineers and other support Arms. Development may be preceded by research carried out within MEXE and may be entirely within the establishment, down to the last nut and bolt or may be by development contract with industry. Sometimes the user's requirement can be met by tests of a commercial equipment. Recently the facilities at MEXE have been used for purely civilian tests on commercial plant and equipment for industry.

MEXE numbers about 800 and is organised under the Director in five technical wings. These are: (1) Bridging and Structures; (2) Mechanical; (3) Fuel and Power; (4) Plant, Roads and Airfields and (5) Materials Research. An administrative branch is responsible for finance, staff, stores, accommodation and transport. Technical support is provided by well-equipped laboratories, workshops, drawing office, library, photographic section and cinema.

Outside and near MEXE are large areas for testing and evaluating plant, including test tracks, test slopes, tilt rigs, dynameter cars. Two other sites are used for testing POL items (petrol, oil and lubricants) under safe conditions.

MEXE forms part of M.G.O.'s organization, being one of the Army Department's R & D Establishments and having close links with the larger establishments such as RARDE and FVRDE. The work falls into two categories, namely research and development. Research absorbs about 20% of the effort and is carried out to a programme agreed with Chief Scientist (Army). Ideas for research spring from MEXE, the users or almost anywhere, but chiefly the programme is drawn up on the advice of the Wing Superintendents. Development on the other hand is to meet specific and stated requirements. A long complicated cycle has to be gone through at every stage in a development project. Efforts during the years since World War II have had the result of making this process much more complex, with far more committees to be convinced. Thus a time from initiation to production of seven years is hardly enough for a project—in sharp contrast to the 11 months needed to get the famous Bailey Bridge from the back of the envelope sketch into the hands of the troops in 1942. It is doubtful if this long complex process really saves money compared with more straightforward measures.

FIG. 1. MEXEFLOTE 120 ton powered raft, 120 ft. × 24 ft.

FIG. 2. Two side carried MEXEFLOTES on L.S.L.

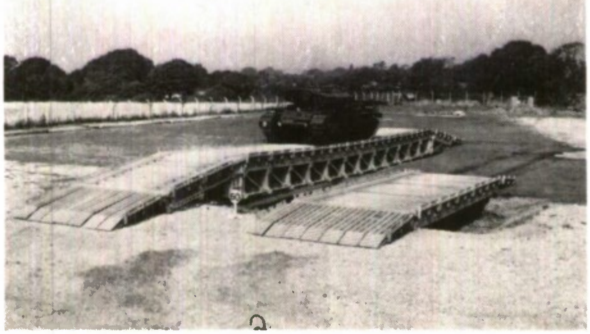


FIG. 3. Medium Girder Bridge, double and single storey.

Bridging and Structures Wing

This wing deals with a variety of projects and largely the equipments are completely designed at MEXE down to the last detail. This is because military bridging has no counterpart in civil life, where bridges are tailor-made for each site. The Army requires portable—sometimes airportable—demountable bridges which can be put together, launched, decked down and opened to traffic in very short times. The more important equipments going through development at the present time are the Harbour and L.S.L. Pontoon Causeway Equipment (*MEXEFLOTE*), the Medium Girder Bridge (M.G.B.) and the Airportable Bridge (A.P.B.).

MEXEFLOTE. This consists of steel boxes about 20ft. × 8ft. × 4ft. 9in. Three types are used, bow, centre and stern, and these can be assembled to make a raft 66ft. × 24ft. with 60 ton capacity (Fig. 1). Powered by two 75 h.p. *Harbourmaster* O.B. motors the speed attained is about five knots.

The main use of this equipment however is with the L.S.L., which side carries two causeways 126ft. × 24ft. on each side (Fig. 2). These can be allowed to fall into the sea, and be connected together end to end to make a 250ft. causeway. The bow doors of the L.S.L. open directly onto this causeway, allowing the traffic to roll ashore. Severe shocks were caused when the first complete rafts were dropped from the ship's rail. This was because of the " belly flop " causing high deceleration (*e.g.* 30g). A more sophisticated hook design was made which disengages after only 16° of rotation. Thus the raft drops almost vertically and then pushes away a wedge of water as it slowly rotates to a horizontal position.

Individual pontoon units are connected by posts in slots thus giving no projections. The equipment is designed to operate in 5ft. waves and to survive in 9ft. waves. The slots will accommodate bollards, fenders, anchors and winches. This equipment is now in production and the U.S. have ordered a set for evaluation to meet their own requirement.

M.G.B. This is designed as an all-welded aluminium alloy hand-built bridge up to 100ft. span capable of taking Army tanks. It is a deck bridge in which the upper surfaces of the two girders and the deck units between form the roadway. A shallow single storey version (Fig. 3) serves for short spans or light loads, and a double storey makes the 100ft. span. The double storey uses the same box girders and decking with triangular panels beneath, and junction panels at each end to give ramped access.

The equipment is carried on pallets on trucks or trailers. These can be pulled off quickly and unstrapped to give the complete stores for building

and launching: 11 pallet loads will produce either one 100ft. bridge or three 30ft. spans. Bridges are assembled on a launching frame with built-in levelling devices. A single central launching nose is used, just wide enough for a walkway so that a small party of men can carry across the roller on which the launching nose runs.

So far trials have shown that 25 men can erect the 100ft. bridge in one hour and eight men can build the 30ft. span in 20 minutes. Fatigue trials in which a *Centurion* tank crossed the bridge 12,000 times have been carried out. One bridge is at present in Australia for tropical trials and considerable interest has been expressed both by U.S. and F.R.G. sources.

A.P.B. This is designed to provide an airportable equipment adaptable to give either a raft, floating bridge or dry gap bridge as required. The basic unit is a light alloy box 12ft. × 4ft. × 1ft. 3in. weighing about 550lb. The top of the box forms the deck and the structure of the box provides girder strength in the dry gap and buoyancy in the raft and floating bridge rôle. The boxes are joined at the bottom along the 12ft. edge by a dovetail tension joint and locked together by shear tension joints at the top edges. At the ends of the bridge are 12ft. tapered ramps fitted to the same connections on the boxes. Thus, only two components go to make the dry gap bridge (Fig. 4).

For the floating bridge, pneumatic floats are added at each end of the boxes for additional buoyancy and they also give a streamlined shape so far as the river current is concerned. In addition, hydraulic articulation boxes are inserted between the girder boxes and the ramps to enable adjustments to be made to the slope of the ramp for varying bank conditions. Thus, only four components go to make a floating bridge.

Two more components are required for the raft (Fig. 5). Rigid sponsons at the four corners take the place of pneumatic floats and on these are mounted 45 h.p. outboard motors in a ring frame to give 360° steering. These also serve as carrying cases for the outboard motors. Triangular corner pieces complete the raft and give it good propulsion characteristics in all directions. A bridge set will give either four rafts, 192ft. of floating bridge or four dry gap bridges. It is carried on special light trailers and can be towed behind a Land Rover. One quarter set can be carried in an Argosy aircraft. Trials of this equipment have gone well and users in FARELF are so far pleased. U.S. and Australia are showing interest.

Research projects in the Bridging Wing include an investigation into inflatable structures. These have possibilities for light scale bridging (Fig. 6) and as fascines, *i.e.* devices to be dropped into

FIG. 4. Airportable Bridge.

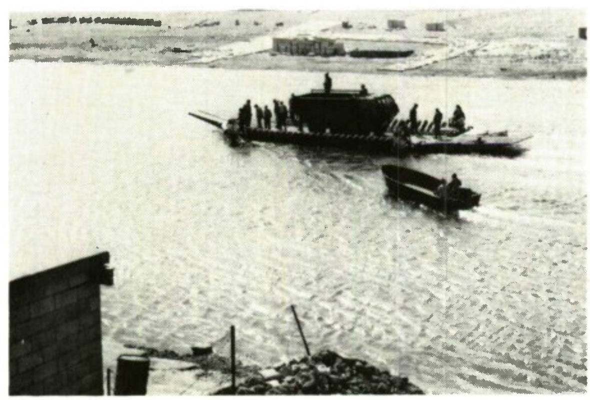


FIG. 5. Class 16 Airportable Raft.

FIG. 6. 20 ft. Inflatable Bridge.

FIG. 7. Inflatable Fascine.

FIG. 8. Two-man Individual Protection Kit.

FIG. 9. Command Post Shelter.

ditches to allow tracked vehicles to cross (Fig. 7). There are several other possibilities for inflatables.

Field Shelters are developed by this wing and are supported by considerable research into the effects of blast and heat flash. A simple two-man individual protection kit weighing 2lb. has been developed (Fig. 8). This covers one end of a weapon pit and the earth is piled back on top of it, giving good cover. For command posts a simple shelter kit is available (Fig. 9) consisting of pickets, ties, arch members and a reinforced membrane. The excavation is made by machine, the pickets can be quickly driven in and the structure completed very easily. The membrane is spread over the arches and round the pickets to form a vertical wall. Earth is then back-filled giving at least 18in. cover.

Mechanical Wing

One of the main tasks is the development of a series of materials handling projects. Partly this is evaluation of what is available commercially and partly the design of new items.

The Rough Terrain Crane (Figs. 10 and 11) is required for a variety of logistic support tasks operating over beaches and unloading craft in shallow water. It is ruggedly constructed and has high mobility. It is mounted on four wheels with 24 × 29 tyres and does not require outriggers. The jib is telescopic and all operations are hydraulic. Both axles steer so that the turning radius is about half that of a normal vehicle. Crab steering is also possible and often is useful. It is powered by a Rolls Royce C8 engine, through torque converter, and has disc brakes giving full control during or after wading. Tests have shown that it will negotiate 1 in 2·5 slopes, travel at 38 m.p.h. and has outstanding rough terrain mobility. It will lift 10 tons maximum when static and seven tons on the move.

The Rough Terrain Fork Lift Truck (Fig. 12) has been designed to meet an air-portable requirement. The all-up weight is 6,000 lb. and it lifts 4,000 lb. It is four wheel drive and four wheel steer and the driver is positioned well forward and to one side so that he can see his forks and see past his load. A prototype was designed and made in MEXE workshops in seven months. A decision to do this was not taken until a careful survey of trade patterns had revealed nothing suitable to meet the requirement.

At the present time a review is being made of the Army's requirements for pallets and containers. Clearly these must be integrated into the supply system and means of handling from factory or depot all down the line to the user must be provided. This will include fork lift and pallet trucks, conveyors, gantries, banding and strapping materials, racking systems, etc.

Materials handling is an all-Arms problem and indeed a tri-Service one, and we have recently been asked to select and try out a suitable fork lift truck for the new Assault Ship. This demanded exceptional gradient performance, good manoeuvrability and a compact layout.

The wing is also responsible for the outboard motor development and brackets used on the APB. Other projects include machines for burying mines mechanically at high rates and for surface dispensing for those occasions when this is acceptable.

An interesting project is the development of a portable desalination plant. The requirement is for a plant weighing less than 4,000lb. to produce 5,000 g.p.d. Nothing is commercially available to meet this. Vapour compression plants run into difficulty with water of high salinity (*e.g.* Persian Gulf); vacuum vapour compression was more successful, but the most promising is a reverse osmosis process. This requires special membranes through which salt water is forced under pressure. Considerable development is in hand on this process both in the U.K. and U.S. No heat is required, only power to operate the pumps.

FIG. 10. Rough Terrain Crane.

FIG. 11. R.T.C. wading in 6 ft. of water

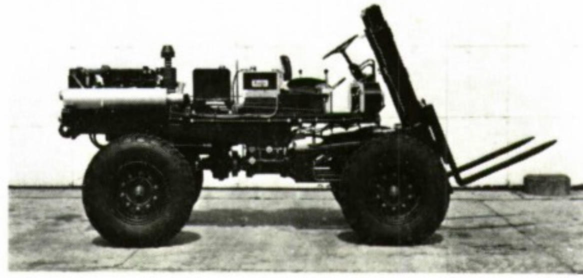


FIG. 12. MEXE built Mock-up of Rough Terrain Forklift Tractor.

FIG. 13. Medium Dracone moored to Pump Raft at Little Aden.

Fuel and Power Wing

This has three major responsibilities—POL, Electric Power and Engine Testing.

In POL (Petrol-Oil-Lubricants) the task is to develop equipment for the storage and handling of bulk fuel from the tanker over the beach and right up to the aeroplane in a forward airfield. This is part of the limited war concept. To get the fuel from the tanker ashore, use is made of towed flexible barges or Dracones which have been developed for this purpose. Made of tough, synthetic rubber-proofed fabrics, these can be rolled up and carried in a cargo net and launched over the side of the tanker. Internal gas filled tubes keep the empty dracone afloat and it is filled through a towing hose attached to the nose. This can be done with the tanker under way. Dracones when full are cast off and picked up by a workboat which takes them to a pump raft moored in shallow water off shore (Fig. 13). A stripping pump puts the fuel ashore through a beach hose into a shore storage depot. Here are pumps, filters, water separators and a light alloy pipeline with victualic couplings which can be used up to 25 miles. Storage is in pillow tanks (Fig. 14) of 10,000 and 30,000 gallons.

FIG. 14. 30,000 gallon Pillow Tank.

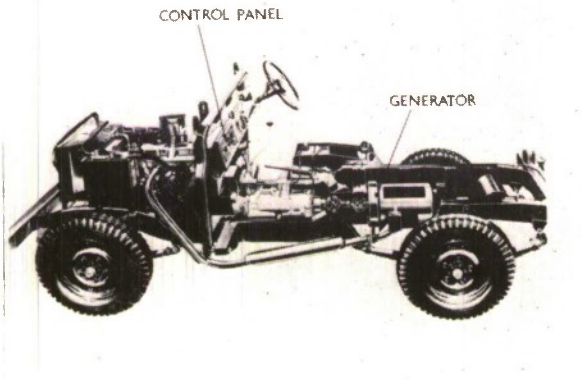


FIG. 15. English Electric Land Rover with 15 kVA, 400 cps Generator.

The medium dracone is 225ft. long, 9ft. diameter and holds 81,000 gallons.

Synthetic, flexible POL-proof materials are very susceptible to high temperatures. To prove their suitability MEXE has its own outstation at Little Aden where a complete POL system was set up over a two mile distance from shore to airfield. Trials on pillow tanks, dracones, flexible hose lines, pumps and filters, *etc.* at this station have been most valuable.

The main interest in the electrical field is in the 400 cps generating sets and field tools. A family of 5, 10 and 20 KW, 400 cps, 3 phase generating sets is under development to provide power in the field for a wide variety of general and special purpose applications. These and the growing variety of hand tools will replace the conventional air compressor and show remarkable savings in weight, greater efficiency and less noise. English Electric make a conversion kit for a Land Rover. This is a 15 Kva alternator fitted under the chassis (Fig. 15) and it makes no difference to the carrying capacity of the Land Rover, providing enough power to operate roadbreakers, rock drills, chain saws, concrete vibrators, submersible pumps, *etc.*

The Army are interested in silent power generation, a need which may be met with Fuel Cells. Fundamental research and testing of fuel cells is an Admiralty responsibility and MEXE enjoys close liaison with the Admiralty Materials Laboratory in assessing the Army applications of any possible fuel cell system. The U.S. already have small hydrazine fuel cells out for troop trials.

Another important electrical requirement is lightweight, portable field welding equipment. This requirement has increased in scope with the new materials such as aluminium alloys, high tensile steels and maraging steels. An all-purpose unit is under development with an automated selector of voltage, wire feed speed, shielding gas mixture and welding process interlocked with a coded drum for different types of filler wire (Fig. 16).

Engine Type Testing is carried out in two well equipped test houses (Fig. 17). Most of the testing is for type approval of IC engines for industrial applications in plant and equipment for the Joint Services. In addition, tests are carried out on

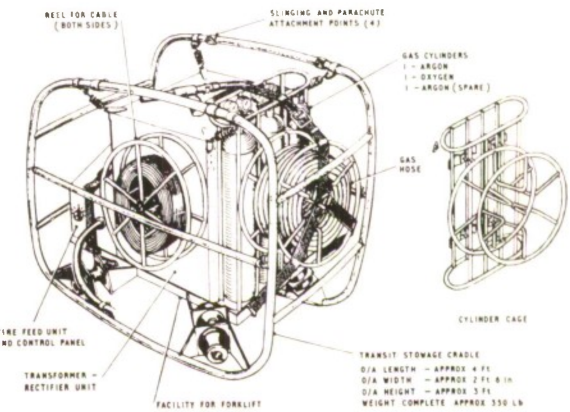


FIG. 16. Lightweight Field Welding Equipment.

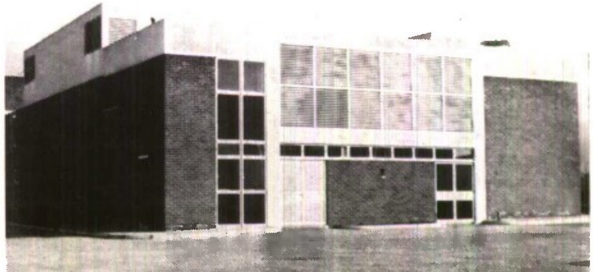


FIG. 17. Industrial Engine Test House.

engine-driven equipment, particularly pumps and generating sets. Type tests are also made on electric motors and starters and on generating sets for type approval so that they may be included in SSM(L). An interest is taken in gas turbines which have special problems in static rôles when subjected to dust or leaded fuel. There is also a project to assess the military advantages of unconventional engines with special emphasis on silence, lightweight and multi-fuel potential.

Plant, Roads and Airfields Wing

This has a variety of projects. The Army's requirements for earthmoving and road construction plant are met from industry as far as possible. Over the years MEXE have developed testing facilities on two large sites (800 acres) which are unique. In 1959 MEXE were made the recognized Authority for Testing Construction Equipment in the U.K. This is done on a repayment basis and machines are tested against a B.S.S. or Test Code, or against tests agreed between MEXE and the manufacturers. Test Certificates and Reports are issued which are of considerable value in fostering overseas sales of U.K. made equipment.

Sometimes special machines are required. Fig. 18 shows a light mobile digger developed by MEXE for digging slit trenches, weapon pits and command posts. The output is extremely high and a two man weapon pit can be dug in about one minute. Another Service requirement is the breakdown of plant for helicopter lifting (Fig. 19).

FIG. 19. BK 10 Grader knockdown for Helicopter carriage.

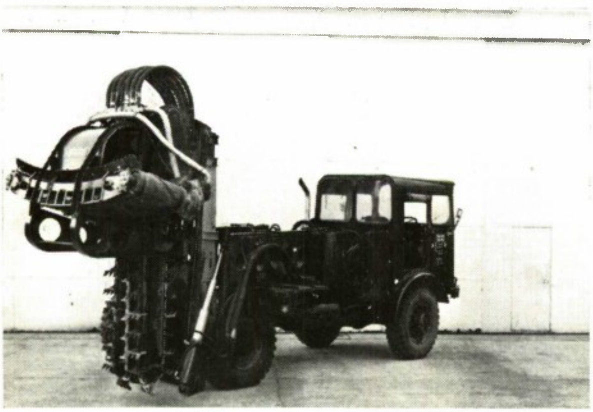


FIG. 18. Light Mobile Digger.

Work on airfields is directed towards the rapid construction and surfacing on natural ground. This is done with mats and membranes. Membranes are neoprene coated nylon where the ground is hard enough and also as helicopter pads (Fig. 20) where dust must be prevented. The mat is required to provide a load bearing surface to replace the old World War II PSP which is too heavy and not strong enough for modern V/STOL and transport aircraft. The mat is an extruded aluminium plank, hand laid, with staggered joints. The planks are laid at 45° to the runway axis so that the ripple which builds up as the aircraft comes to rest can "evaporate" along the edges.

Fig. 21 shows a road trackway and the method of laying it. This too is extruded aluminium planks. The trackway, put down in minutes, will take normal wheeled traffic over very soft ground.

MEXE are also developing a system of Terrain Evaluation which is an attempt to classify bits of landscape from aerial photo maps in physiographic terms. The classification will yield information for the Engineer as to where he can build his road or airfield and where he can find water, rock or gravel. Predicting can be made on inaccessible sites and some information can be obtained as to the 'going' for vehicles.

Materials Research Wing

This offers support to all the others. In the field of plastics a study of the behaviour of glass fibre reinforced resins in different atmospheres has been made. Only a small proportion of the true strength is available in water and methods have been found of improving the performance. Plastic foams are also studied and methods of joining airfield membranes in the field.

Work on ultra high strength steel, used for a bridging project, has mainly been concerned with

FIG. 20. Scout Helicopter on Membrane.

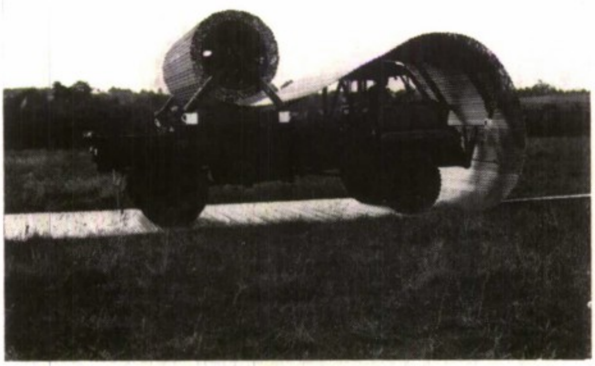


FIG. 21. Class 30 Assault Trackway.

the 18% Ni maraging steels. Welding parameters for this have been established and work on the fatigue performance and stress corrosion behaviour continues. MEXE has close liaison with the Naval Department in work on high strength structural steels.

Research on Aluminium Alloys has concentrated on the Al-Zn-Mg types which are weldable and have medium high strength. They are the only aluminium alloys which combine strength with weldability, but several metallurgical problems have been revealed, *e.g.* micro-cracking at welds, stress corrosion in welds and in parent material. The alloys are sensitive both to composition and manufacturing technique and close specification will be required.

Fatigue is a subject on its own. Because of the increased use of new alloys and steels in bridging equipment with their high static strengths and limited fatigue life, it has been necessary to evolve a quite different design philosophy based on fatigue approved testing. This has involved a study of the stresses to which bridges are subjected and an analysis of the likely traffic loads. Cumulative damage is not really understood, but work is in hand to assess its effects and to develop techniques for indicating the amount of fatigue life left in a component after so much service.

In this short paper it has not been possible to touch on all the projects and research which MEXE undertakes. Sufficient has been said, I hope, to indicate the wide field of interest covered in the work, which keeps an enthusiastic team on its toes and makes for a happy establishment.

The R.N.'s first Satellite Communication Terminal aboard H.M.S. 'Wakeful' was successfully demonstrated before 15 representatives of foreign navies on 24th May. Dr. Glanville Harries is here seen with Naval Attaches from South American Countries.

H.M.S. *Eagle*, the first ship of the Royal Navy fitted with the Improved Communication System

AN IMPROVED MF/HF COMMUNICATION SYSTEM

For Ships of the Royal Navy

With the introduction of more sophisticated weapons systems in ships of the Royal Navy and the need to communicate over greater ranges, it has been necessary to improve ship-to-ship, and ship-to-shore communication in order that the full fighting potential of the fleet may be exploited. As a large proportion of communications equipment fitted in the fleet in the immediate post war years was outdated and did not warrant from a technical or economic point of view expenditure on maintenance or improvement, replacement of the older equipment was considered essential for reasons of reliability, maintainability, performance and cost effectiveness.

Because of range requirements, the absence of a satellite system in the immediate future, and the unique propagation characteristics in the Medium/High Frequency band, the development of an improved MF/HF communications system was carried out and these systems began being fitted in R.N. Ships three years ago.

Since Naval Communications frequently involve ship-to-air circuits and having regard for the increased speed and ranges of service aircraft, fairly rapid frequency changing techniques were adapted to maintain maximum circuit efficiency at various ranges between ships and aircraft. For similar reasons, narrow band modulation tech-

niques utilising the maximum amount of radiated power in the intelligence, such as found in S.S.B. suppressed carrier modulation, were adopted. The equipment design also provides for the transmission and reception of the more conventional modes of modulation so that communication compatibility is maintained with organisations and authorities which as yet have not adopted Single Side Band modulation techniques.

The use of these techniques however, called for an accurate and stable frequency source at each and every terminal. Because of the large number of radio frequency equipments carried on board H.M. ships, a master frequency standard unit was developed and from one of these units, fitted in each terminal, the radio frequency equipment is controlled through a frequency standard distribution system.

From the common frequency standard, the radio frequency equipments are designed to generate the working frequency required by frequency synthesis techniques whilst still sensibly maintaining the accuracy and stability of the standards.

In a typical installation up to three master frequency standards are fitted, together with a frequency comparator unit. This system allows a comparative check between standards and provides facilities for a faulty standard to be removed immediately from the circuit.

Each radio frequency equipment (transmitters and receivers) is fitted with decadal frequency controls and digital frequency presentation. Frequency switching is in 100 c/s steps over the MF/HF bands. Since each of the equipments can be locked to the frequency standards they may be left unattended for long periods and considerable saving in operating manpower is achieved. Facilities are provided, however, to unlock the receivers from the master frequency standards so that they may be used to receive less stable transmissions by an attending operator.

The control of incoming and outgoing circuits and the associated equipment is centred around a control and monitoring console, manned in small ships by one rating and in large ships by two. Facilities are provided on the console for monitoring and level control of all receiver and transmitter circuits, monitoring of the waveform of their signals, auto tuning of the high powered transmitting equipment (located in a remote office), monitoring of the transmitter output power and its state of match to its associated aerial. R.F. linearity test facilities and telephonic communication to all remote control positions throughout the ship are also provided. Routing of the transmitter and receiver lines to the remote control positions are controlled from a central exchange adjacent to the console. Since re-routing of circuits is carried out infrequently, even during operations, only manual switching facilities are provided.

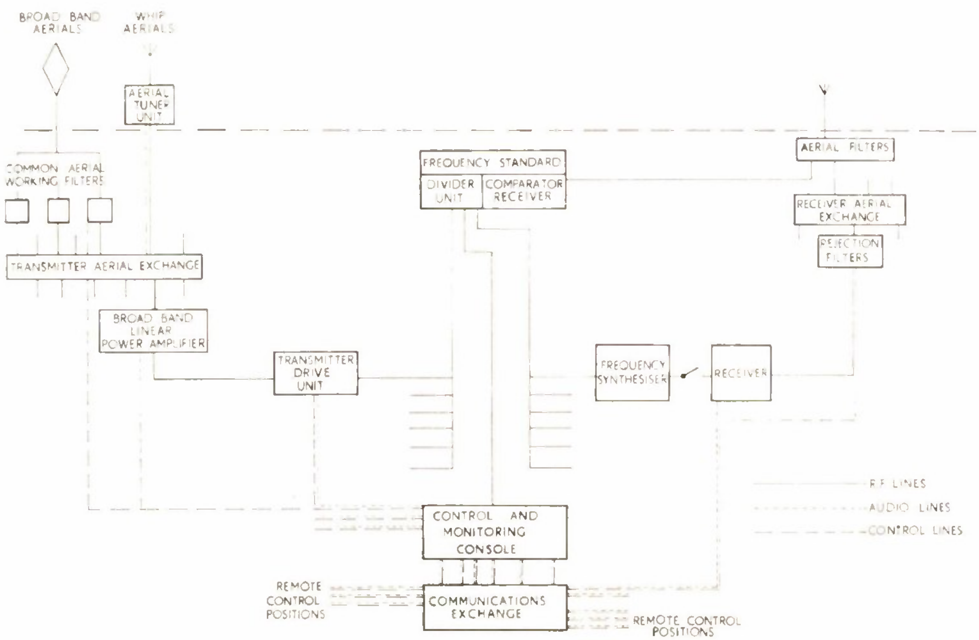


Diagram of installations

All outgoing lines from the central exchange pass through the control console so that the processed audio signal passed to the transmitters is correct. Within the modulator unit of the transmitter, the audio signal modulates its associated carrier and appears at the output as a low level modulated signal of the required form of modulation (Carrier Wave, Modulated Carrier Wave, Double Side Band, Single Side Band (Suppressed Carrier), and Frequency Shift, *etc.*). By means of wide-band linear power amplifiers located in a remote screened office the low level modulated r.f. signal is amplified to its full output peak envelope power. Depending on the radio frequency of the signal the r.f. power is routed through one of a number of circuits of a transmitter aerial exchange to the appropriate aerial.

Where practicable, broad-band aerial systems are employed covering frequency band ratios of the order of 3 : 1. These aerials generally utilize part of the ship's structure such as a mast or a funnel with the addition of vertical wires to form folded monoples. Such an arrangement requires no modifications to the mast structure such as insulating the base. Because of their wide-band properties more than one transmitter is capable of radiating from the structure simultaneously. Feedback of power from one transmitter to its neighbour is prevented by the inclusion of narrow-band filters in the output feeder of each transmitter. The technique of simultaneous radiation of a number of transmitters on a single aerial has become known as Common Aerial Working. The use of the technique aboard ship gives the most attractive advantages of minimising the number of transmitting aerials in a very confined space, producing considerable improvement in aerial radiation characteristics and limiting radiation hazards to crew and weapons. On frequencies outside the range of the broad aerials, vertical " whip " type aerials, one for each transmitter, are employed. Their matching to the associated feeder system is derived from tuner units mounted at the aerial base.

Whip type aerials are used for reception. Since their terminal impedance mismatch to the associated feeder is of less importance than in the transmitting case, no matching circuits are employed. On entering the receiving compartment, the feeders are fed through low pass filters, so as to minimize interference from local transmissions on higher frequency bands, to a receiver aerial exchange.

In addition to providing switching facilities to the different receivers the exchange houses banks of narrow-band stop variable frequency filters. These may be tuned to the frequency of the local transmitters and limit undesirable potentials which would otherwise be presented at the receiver input terminals. In the absence of the local transmission the associated band stop filter is switched out of circuit to facilitate simplex working.

In common with the transmitter circuits, and for similar reasons, common aerial working is employed for reception. However, because of the less stringent impedance matching requirements wider frequency bands can be accommodated. To give greater flexibility, facilities are also provided to enable receivers to be switched to one of a number of aerial lines, since conditions frequently exist where reception on one aerial is superior to another for a given frequency. In spite of protection offered to the receivers by input filtering, overload and ultra linear input circuits are used to prevent damage and the generation of interference. The audio output lines from the receiver are connected to their relevant remote circuit communications exchange.

All office r.f. equipment is housed in sealed cabinets of approximately 2 ft. × 2 ft. floor area and 6 ft. in height. Where more than one equipment is housed in the cabinet, such as receivers and transmitter drive units, the cabinet is subdivided to give good electrical screening. All cabinets are resiliently mounted to the deck to improve the reliability of the contents under conditions of shock and vibration. They are also designed to enable the contents to be cooled by a closed forced air ventilation system.

Development of the system, and the equipment forming the system, was conducted by the Royal Naval Scientific Service at A.S.W.E. in conjunction with six internationally known contractors of the communications industry. With the exception of one type of equipment, the broad-band transmitting power amplifier, all others were specifically designed for the system to Ministry of Defence Specifications. In the case of the power amplifier the manufacturer's basic design was modified to suit the ship-borne environment.

ANALYSIS AND SIMULATION OF MAIN MACHINERY PNEUMATIC CONTROL SYSTEMS

J. B. Spencer, B.Sc., R.N.S.S.
Ship Department, Ministry of Defence (Navy).

SUMMARY

In order to give some guidance in the setting up of boiler control systems to produce the best possible transient response, each system has been analysed and simulated on an analogue computer. In particular, attention has been directed to the study of the control of boiler pressure, fuel and air supply. These systems are considered in some detail, and brief mention made of similar studies undertaken on the other systems necessary for satisfactory control.

Introduction

The present generation of R.N. ships are so designed that it is possible to control the main machinery from a central control room. It is possible to maintain this condition for long periods of time, and select any power from stand-by to full power as and when required. Furthermore it is necessary to be able to obtain rapid power changes, particularly in the case of aircraft carriers fitted with steam catapults. To meet these requirements automatic combustion control equipment is fitted using conventional pneumatic components.

The fuel system selected to meet the stringent operational requirements employs spill atomisers in which the spill and supply pressures are both varied simultaneously. The reasons for making this choice are most clearly demonstrated by reference to a typical spill atomiser output curve (see Fig. 1). The simplex characteristic is the pressure/flow relationship with no spilled flow. Above this characteristic the curves are of supply flow for a constant spill pressure, and below the characteristic the curves are of burnt flow for constant spill pressure. Lines of constant spray cone angle are

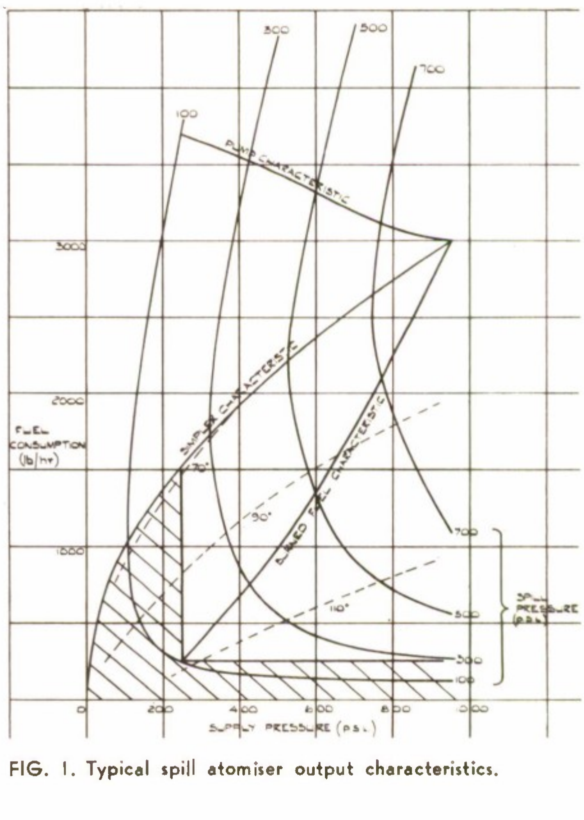


FIG. 1. Typical spill atomiser output characteristics.

also shown. It is not practicable to operate in the shaded area because of inadequate atomisation of the sprayed fuel. Thus for a maximum supply pressure of 950 p.s.i. it can be seen that a maximum turn-down of 12 : 1, whilst maintaining good atomisation and a reasonable spray cone angle, is obtained by following the curve designated " burned fuel characteristic ". To use this characteristic it is obviously necessary to vary spilled and supplied fuel pressure simultaneously. Selection of a burned fuel characteristic uniquely determines the associated supply pump characteristic which is also shown on the diagram.

In the plant under consideration a master control signal is produced by variations in boiler drum pressure from the set desired value. This master signal is then used to provide desired values of spill and supply pressures, and also of air flow or register draught loss. The analysis and simulation was initially concerned with optimising the response of the two interacting control loops of the fuel system. Obviously, however, one system cannot be considered in isolation, in particular the combustion air control loop must also be optimised in order to provide a satisfactory fuel/air ratio. Equally it is essential to investigate the water level control system and other related systems. In the first instance each of these systems was investigated separately, and this method has been the most successful in producing results which are of value to the operators. An overall simulation of the complete ship installation was, however, carried out of which brief mention will be made, more detail can be found in reference 1.

Analysis of the Fuel Control System

A diagrammatic representation of the fuel control system is shown in Fig. 2. It can be seen that the master control signal is used to provide desired values to two loops, one positions the valve controlling steam to the fuel pump turbine, and hence controls supply pressure, the other positions the spill valve regulating the amount of spilled fuel, and hence controls spill pressure. In this example the supply pressure is varied linearly with the master air control signal from 250 p.s.i. to 950 p.s.i., and the spill pressure from 100 p.s.i. to 900 p.s.i.

In order to simulate and investigate the performance of the system it is necessary to analyse the characteristics of the individual components.

Atomiser characteristics similar to those of the typical curves shown in Fig. 1 can be represented by the following relations:

$$q_1 = 300\sqrt{P_1 - \cdot 955P_2}$$

$$q_3 = \frac{27P_2}{\sqrt{P_1 - P_2}}$$

$$q_1 = q_2 + q_3$$

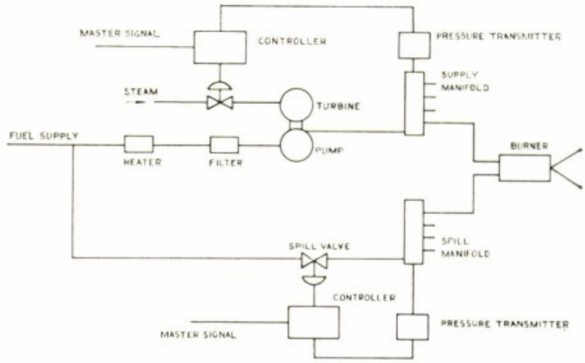


FIG. 2. Fuel control system diagram.

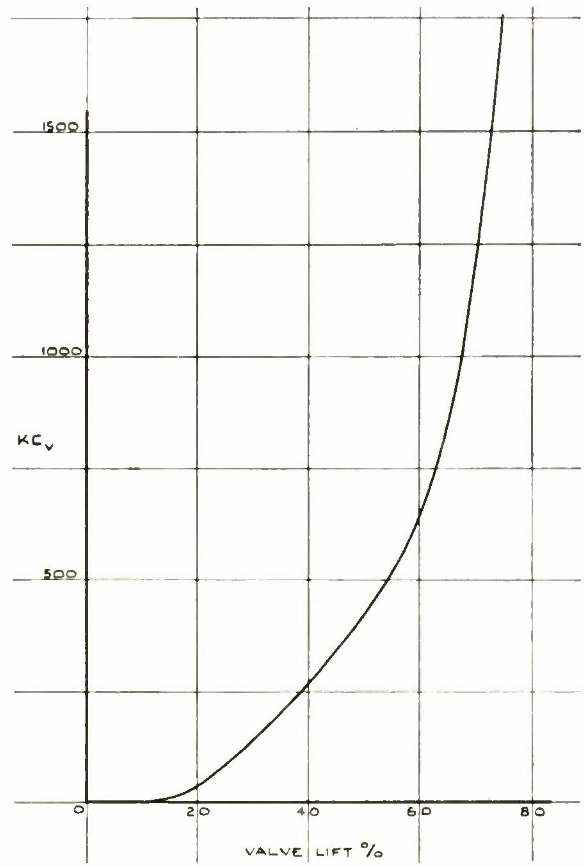


FIG. 3. Typical spill valve characteristic.

where q_1 is supply flow (lbs/hr), q_2 is spilled flow, q_3 is burnt flow, P_1 is supply pressure (p.s.i.), P_2 is spill pressure.

The spill valve characteristic can be represented by an equation of the form:

$$q_2 = KC_v\sqrt{P_2 - 40}$$

where KC_v is the valve characteristic, the particular valve used in this example has the characteristic

shown in Fig. 3 (depicting KC_v plotted against valve lift). A simple by-pass control valve is designed to maintain the inlet pressure to the fuel pump at 40 p.s.i.a., the spilled fuel is returned to this inlet.

Analysis of the characteristic curves of a positive displacement fuel pump (the type in general use) revealed the following relations:

$$T_t = 150L - 12{\cdot}5$$
$$T_p = 0{\cdot}0672P_1 + 29$$
$$\dot{n} = 6{\cdot}83\,(T_t - T_p)$$
$$q_1 = 10n - (2520 + 5{\cdot}04P_1)$$

where T_t is turbine torque (lb. ft.)
T_p is pump torque (lb. ft.)
n is pump speed (r.p.m.)
and L is the fuel pump turbine steam valve lift as a fraction.

It had been assumed in the derivation of the above equations for the fuel pump that as a result of system design the fuel pump output flow would be relatively invariant over the full power range, and therefore the valve supplying steam to the fuel pump turbine would be operating under critical pressure drop conditions throughout. Furthermore a valve characteristic such that turbine nozzle box pressure is directly proportional to valve lift was assumed. In the event these assumptions were fully justified.

The performance characteristics of the pneumatic instruments were obtained by subjecting them, with the appropriate lengths of pipework, to frequency response tests. The results were analysed and the additional or "parasitic" lags which are introduced by the pneumatic components determined. The following approximations to the parasitic lags were made:—

Controller 0·1 second D.V. lag
Valve operator and positioner 0·06 second D.V. lag, 0·5 sec. exponential lag
Transmitter 0·24 second D.V. lag

Measurements on a typical spill valve indicated that the maximum rate of travel was four seconds for full stroke.

Using this information, it is a relatively simple procedure to simulate the system on an analogue computer; D.V. or transport delays were simulated by the second order Padé-type approximation.

Investigation of Fuel System Performance

In a first attempt to find optimum controller settings (proportional bands and integral action times) the Ziegler-Nichols method was used. At various power levels the spill valve was fixed and the gain in the supply loop increased until a steady oscillation could be maintained. The value of the gain and the period of oscillation were noted. Then the procedure was repeated, but this time the fuel pump steam valve was fixed and the gain in the spill loop increased. This method did not show significant variation over the power range, and indicated the following optimum settings:

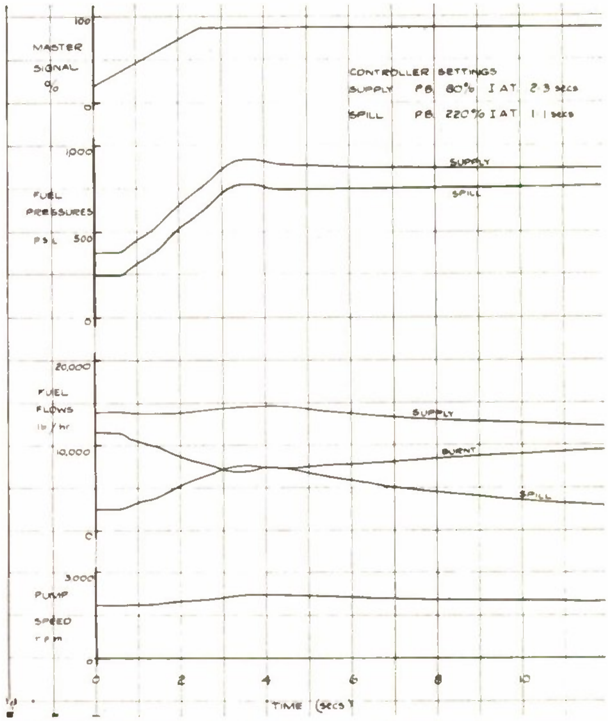


FIG. 4. Computed transient response of fuel system using controller settings found by Ziegler-Nichols method.

Supply controller: Proportional band 80%, Integral action time 2·3 seconds.
Spill controller: Proportional band 220%, Integral action time 1·1 seconds.

This method of determining suitable controller settings has been regularly used on ship installations, and similar results obtained.

To investigate system performance it was decided to compute the response to a change in master signal from 20% to 90% in 2·5 seconds. The transient response to this 70% change using the above controller settings is shown in Fig. 4. Although the pressure responses are reasonably satisfactory, it was felt that the response of the burnt fuel flow could be improved. Further experiments showed that with this particular system improved response could be obtained by using controller settings which reduced the fuel pump speed change to a minimum. The revised controller settings were:

Supply: Proportional band 330% Integral action time 2·3 seconds.
Spill: Proportional band 300% Integral action time 1·1 seconds.

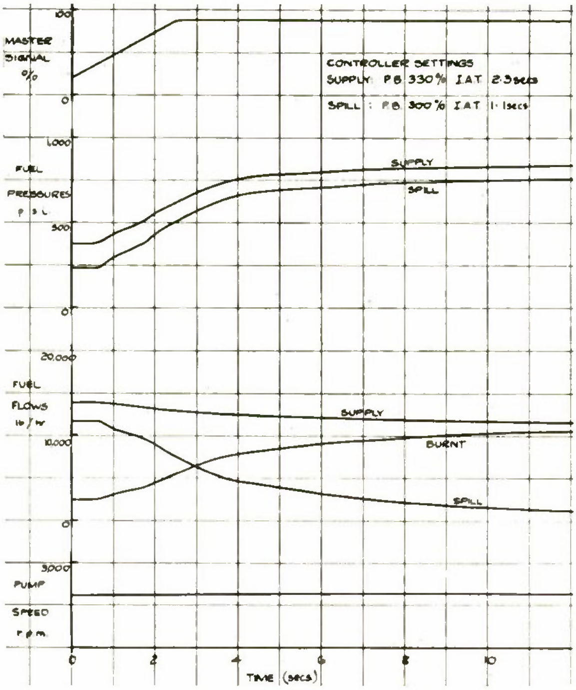


FIG. 5. Computed transient response of fuel system using 'Optimum' controlled settings.

The computed response using these settings is shown in Fig. 5 where it can be seen that there was no measurable change in fuel pump speed, and the burnt fuel flow response was improved. These calculations showed that optimising a system controlling pressures did not produce the optimum response of the fuel flow into the furnace, which is what is actually required. Unfortunately on ship installations fuel flows are not generally measured, and the system must be set to work on the basis of pressure responses. However controller settings similar to the revised values obtained above have been used, although here again some difficulty was experienced in that controllers with proportional bands of this magnitude were not immediately available. To overcome this difficulty inverse derivative units were incorporated in the systems to reduce initially the effect of the tighter proportional bands.

The value of a simulation of this nature is the ease with which modifications to the system can be investigated. The efficiency of this fuel system depends to a large extent on the fuel pressure transmitters maintaining accurate calibration. Obviously quite small percentage errors in transmitters measuring the high pressures involved have a marked effect on the 50 p.s.i. differential in spill and supply pressures that it is required to achieve at full power. It was thought that a differential pressure transmitter would more effectively control the relationship between spill and supply pressures, and be less sensitive to errors in calibration. The control circuits with a differential pressure transmitter in the spill or supply loops are shown diagrammatically in Fig. 6(a) and (b).

The calculated transient response with the differential pressure transmitter in the spill loop is shown in Fig. 7, the same controller settings as for Fig. 5 were used, and the response is almost identical. It was first thought that the differential transmitter could not be incorporated in the supply loop as shown in Fig. 6 (a). In fact a stable system was achieved by reversing the measured and desired value connections to the supply controller, however satisfactory response was difficult to obtain.

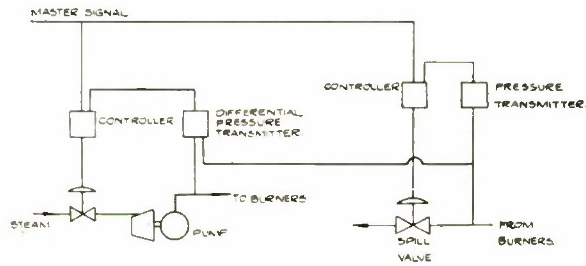


FIG 6a. Differential pressure transmitter controlling supply loop.

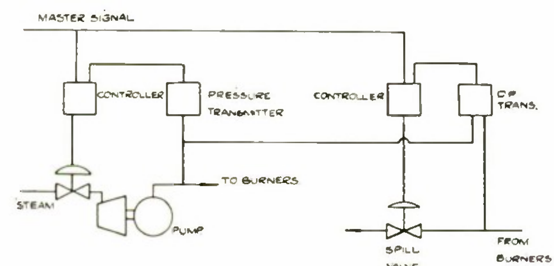


FIG. 6b. D.P. transmitter controlling spill loop.

A differential pressure transmitter has since been tried on a shore test boiler installation where the above conclusions were confirmed. Unfortunately the trial was not completely conclusive because the instrument under test did not live up to expectations. However, it is possible that the additional cross-coupling introduced by using a differential pressure transmitter could make the setting up of the system a little more difficult.

A further brief investigation concerned the fitting of a centrifugal fuel pump instead of the positive displacement type. It was found that if such a pump were fitted it would require quite different controller settings, as to achieve adequate response it would be essential to change pump speed as quickly as possible.

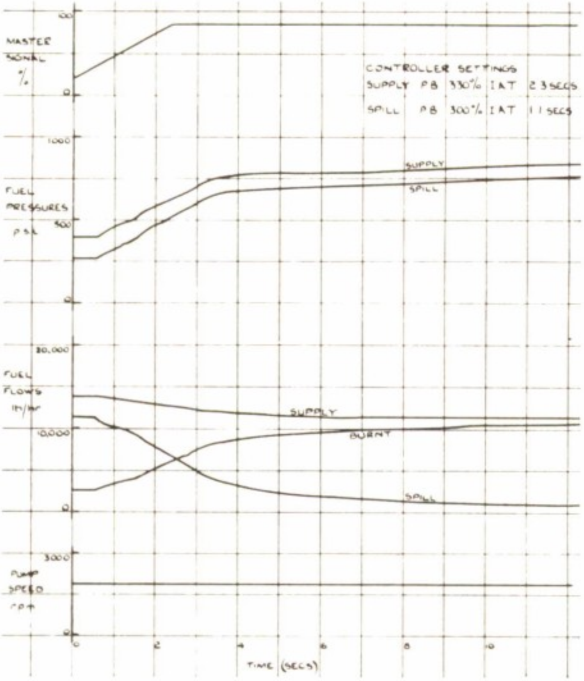


FIG. 7. Computed transient response of fuel system with differential pressure transmitter in the spill loop.

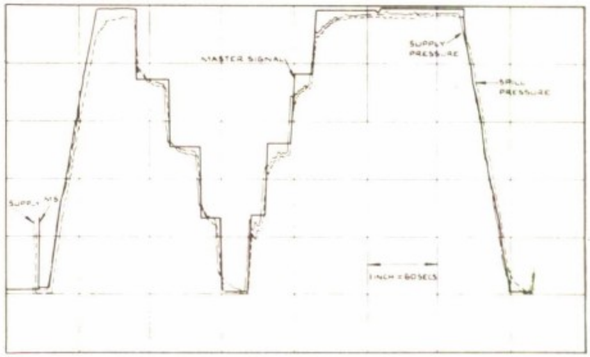


FIG. 8. Fuel system transient response.
Record taken aboard ship.
Controller settings—
Supply: P.B. 200%
Integral action time: 3 secs.
Inverse derivative: 15 secs.
Spill: P.B. 200%
Integral action time 1·8 secs.

Summary of Fuel System Investigation

The calculated transient response of Figs. 4, 5 and 7 were in response to a master signal changing at a rate that is unlikely to occur in a ship installation. However the results did show that it should be possible to set up the fuel control system to give a very fast response, the fuel flow into the furnace, in fact, lags the master signal by an amount that can be represented almost exactly by an exponential delay of time constant two seconds. This result has been used in many subsequent simulations.

Recorded confirmation from ship trials of the applicability of these results is difficult to obtain, a great deal of assessment being done purely on observation. However a record taken on board ship is shown in Fig. 8, it can be seen that quite fast responses were obtained. Controller settings were of the same order of those found in the simulation described above, but differed because the maximum proportional bands obtainable were 200%, and the spill valve had a travel time of full stroke of 12 seconds.

Analysis of the Combustion Air Control System

It is well known that, because of the high inertia of blowers, combustion air control systems have a slower response than the fuel control systems. Consequently, since a satisfactory fuel/air ratio must be maintained, the blower response in many cases limits the overall plant response. Thus an investigation was undertaken on the blower control system to achieve, if possible, a faster rate of response, without recourse to the use of vanes or flaps and the added complication involved by their control.

The combustion air control system is shown diagrammatically in Fig. 9. In the system the master signal is programmed to produce a desired airflow, the measured value of airflow is obtained by taking the square root of the register draught loss. Analysis of the components of the system was very similar to that for the fuel system and detail is given in the Appendix.

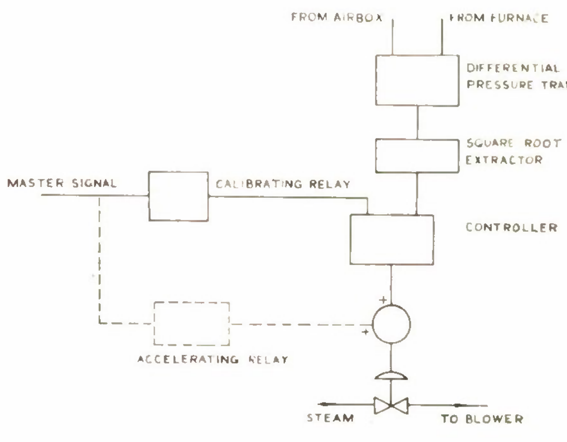


FIG. 9. Combustion air control system diagram.

Investigation of Combustion Air System Performance

For this simulation a more realistic master control signal was obtained from a much simplified (though reasonably realistic) representation of the boiler pressure control. The boiler pressure was assumed to satisfy the following relation:—

$$\frac{dP}{dt} = 12{\cdot}0\,(F-S)$$

where P is boiler pressure (p.s.i.)
F is fuel flow as a fraction of total
S is steam take-off as a fraction of total.

The boiler pressure controller was assumed to be set such that a 50 p.s.i. drop in pressure below the desired drum pressure produced maximum master signal, with an integral action time of 40 seconds. The fuel system was represented by a two second exponential delay. Transient responses were calculated for a steam take-off changing from 20% to 90% in 2·5 seconds.

Ziegler-Nichols tests undertaken to determine the optimum airflow controller settings indicated quite a wide variation with power. However practical experience indicated that the lower proportional bands could not be used because of noise engendered in the measurement of register draught loss. Consequently values were used which were typical of ship settings. In this case with a proportional band of 40% and integral action time of 10 seconds the transient response was calculated. The variation of fuel/air ratio for an increase and decrease in power is plotted in Fig. 10 trace (i). Also plotted on this figure are the programmed (or desired) value of the fuel/air ratio, and the black and white smoke regions which were determined from combustion trials. It can be seen that on increase in power the fuel/air ratio passes through the black smoke region. Improvement was obtained by using an accelerating relay as shown in Fig. 9, with a transfer function of the form:—

$$\frac{Ts}{1+Ts}$$

The response with this relay incorporated is shown in Fig. 10 trace (ii), the accelerating relay time constant T being eight seconds in this case. The corresponding airflow/time curves for the above two solutions are shown in Fig. 11.

An independent investigation was undertaken by Mr. A. Duberley of the Admiralty Engineering Laboratory on a slightly different system. In this system the desired value signal was programmed (effectively squared) so as to eliminate the use of the square root extractor. Frequency response analysis of the combustion air loop was carried out on board ship, and the results used to set up and check a computer simulation. Computed responses confirmed the above conclusions, but this study went on to show that much improved

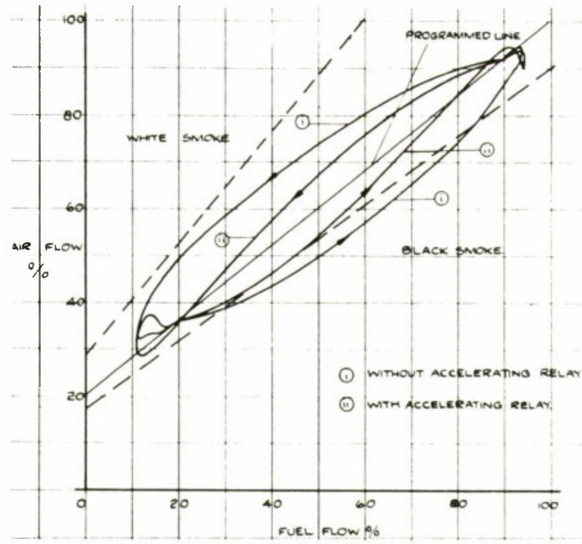


FIG. 10. Computer variation in fuel/air ratio.

response could be obtained by using a variable gain controller. The Ziegler-Nichols tests had shown that the optimum proportional band increased with power, and a controller with this characteristic was incorporated in the simulation. The calculated response to a 30% step change in steam flow (equivalent to the catapult charging load on this ship) is shown in Fig. 12; the proportional band was arranged to increase with master signal from 20% to 86% at full power. In fact, a pneumatic instrument that can perform this function is commercially available, and to confirm the results of this investigation a sea trial has recently been undertaken.

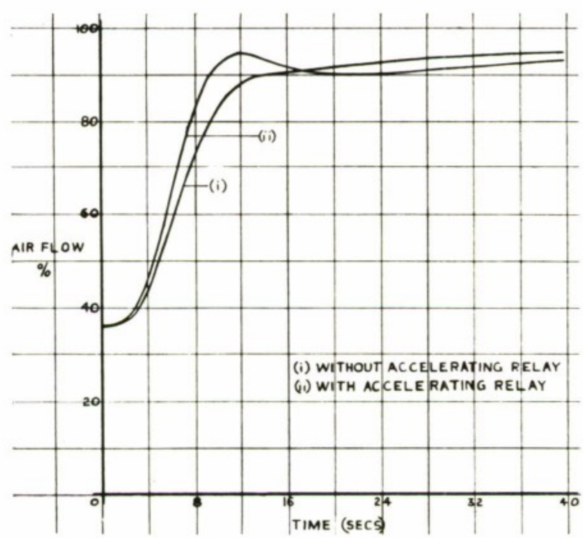


FIG. 11. Computed air flow/time curve associated with Fig. 10.

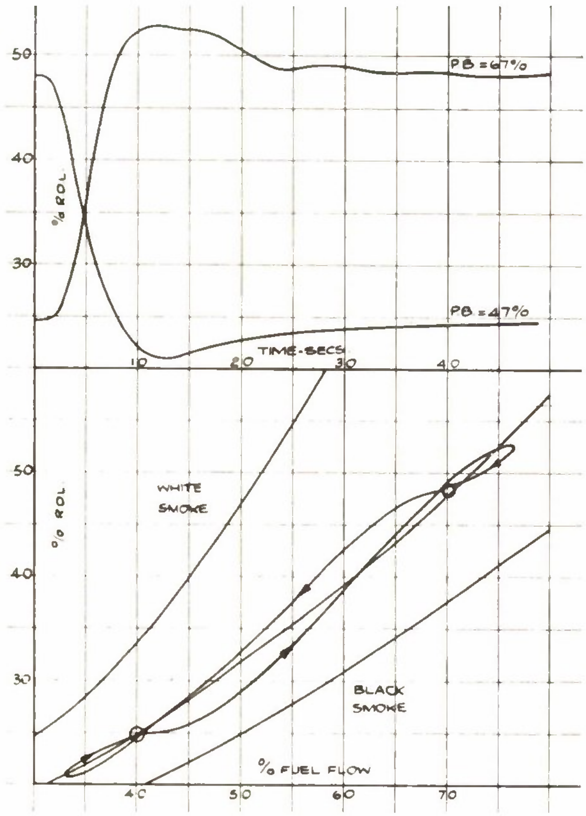


FIG. 12. Simulated transient response of fuel/air ratio when catapulting.
30% step change in stream flow
variable gain controller
P.B. 47% at 40% load.
67% at 70% load.
Integral action time 10 secs.

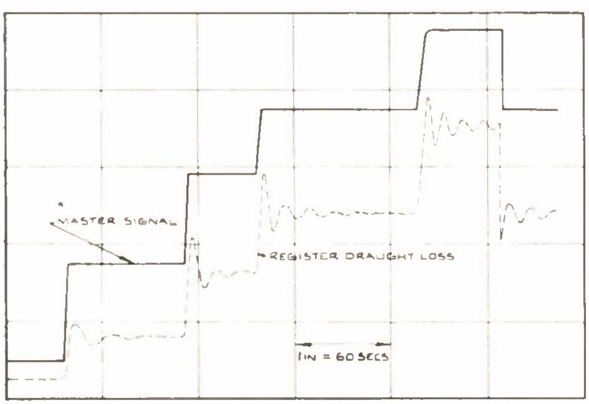


FIG. 13. Combustion air system transient response.
Record taken aboard ship.
Controller setting: P.B. 100%.
Integral action time 7 secs.
Accelerating relay time constant 1·2 secs.

Summary of the Combustion Air System Investigation

These investigations showed that significant improvements could be obtained by selecting and, if necessary, modifying pneumatic instruments to reduce parasitic lags to a minimum. This, of course, includes reducing where practicable the lengths of pipework between instruments. In ships where the faster rates of response are required accelerating relays are now incorporated in the system. A ship record (different from either of the ships investigated above) is shown in Fig. 13, where some reasonably fast rates of change of master signal were imposed. This figure also shows that using a fixed proportional band leads to an increasingly oscillatory response as power is increased, this effect could be eliminated by the use of a variable gain controller as was shown above.

Water Level Control

Investigations of other systems have followed largely as a result of practical experience of using rapid power changes. The simulation of water level control systems presents some difficulty in that it is not easy to construct an accurate representation of the actual water level in the boiler. Various mathematical models have been considered, and use has also been made of experimentally determined transfer functions. Indeed using this latter method quite good correlation with some ship records was recently obtained, and investigation of a 3-element level control system undertaken. No particular conclusions have yet been reached, but it is appreciated that there is little any level control system can do to affect the initial peak (or depression) in level following a rapid power change. If the initial excursion is outside acceptable limits there is no alternative but to reduce the rate at which power changes are made on that particular installation. With the 3-element system it is possible to use a rising level characteristic with change of power, and many ship installations use a steady state level change of the order of two inches from stand-by to full power. Investigations are being continued in conjunction with trials on a shore based boiler, and one aspect under consideration is the use of a larger programmed level change.

The Overall Simulation

In general the control systems associated with the ships machinery were studied each as a separate entity, and typical inputs were assumed in order to calculate transient responses. This approach proved successful, but there was a temptation to consider a complete simulation, including hull and propeller dynamics. Such an undertaking obviously

required a large amount of computing equipment, and even then a number of assumptions had to be made. In particular instrument characteristics and parasitic lags were not simulated, and once more the fuel system was represented by the simple exponential lag. The overall simulation was carried out by the Yarrow-Admiralty Research Department[1], and, considering the assumptions that had to be made, reasonable correlation with actual ship performance was obtained.

Summary

The time allocated for the setting to work of the automatic combustion control equipment on new or re-fitted ships is extremely limited, in particular, there is limited opportunity for determining the settings required for optimum response. Thus any technique which can be used to obtain a better understanding of the processes involved, and give some indication of the approximate values to be used on controllers, is extremely valuable. Analogue simulation has successfully performed these functions, and in the collection of data for the mathematical models the areas where improvement could be made have been revealed.

APPENDIX

Analysis of the Combustion Air Control System

In this particular example the analysis of the blower characteristic curves was undertaken by the Yarrow-Admiralty Research Department, and provided the following relations:—

$$T_{ta} = 0{\cdot}11 M_b - 0{\cdot}116 n_b + 30$$
$$T_{Pa} = 0{\cdot}56 \times 10^{-4} n_b^2 - 0{\cdot}375 \times 10^{-2} n_b$$
$$\dot{n}_b = 0{\cdot}435\,(T_{ta} - T_{Pa})$$
$$Qa = 0{\cdot}00027 n_b$$

where T_{ta} is blower turbine torque (lb. ft.)
T_{Pa} is blower torque (lb. ft.)
n_b is blower speed (rpm), M_b is steam flow to turbine (lb./hr.)
Qa is airflow as a fraction of total

In the relatively simple illustrative example of this paper the steam flow to the turbine was assumed directly proportional to valve lift.

In other investigations a variety of valve characteristics were considered, and the appropriate conditions of critical and sub-critical pressure drop simulated without significantly affecting the overall conclusions.

Frequency response tests of the pneumatic instruments indicated that by choosing those with the smallest parasitic lags the total lag could be represented by a simple exponential delay of 1·5 seconds.

Acknowledgement

This paper includes some results of work carried out by the staffs of the Admiralty Engineering Laboratory, the Admiralty Fuel Experimental Station (now Admiralty Marine Engineering Establishment), the Yarrow-Admiralty Research Department, the Ministry of Defence (Navy) (in particular Mr. D. J. Strong), and a number of H.M. Ships.

Reference

(1) Read, C. M. B., Forrest, J., Naronha, L. *Dynamic Analysis and Simulation of Steam Propulsion Plant.* Symposium on Electronics, Measurement and Control in Ships and Shipbuilding (Glasgow, April 1966) pp. 561-590.

This paper was presented at the Ship Control Systems Symposium held in Annapolis, U.S.A. in November, 1966.

DIVER SHIP MAINTENANCE

CLEANING SHIPS' BOTTOMS AFLOAT USING DIVERS

M. P. Kettle, R.N.S.S.
Admiralty Experimental Diving Unit

SUMMARY

A commercially developed technique using diver operated power tools, to remove marine fouling from the hulls of merchant ships afloat is described, and the application of this process to the Fleet is discussed.

It is concluded that this method of hull cleaning is fast and effective. The value of the system to commercial shipping is obvious, since it satisfies the economic need for a minimum time in port between voyages and it gives the advantages of increased speed or reduced fuel consumption. Should an underwater hull cleaning system be developed for use on naval vessels, it would most usefully be employed in the first instance in cleaning ships' hulls prior to dry docking, so allowing a shorter time in dock. This would result in increased dock availability and the saving of a considerable number of man-hours.

The experimental application of anti-fouling paint underwater is also described as it is the logical following project.

The author does not intend that the article should distract attention from the advanced work being done in the RNSS on hull protective coatings and anti-fouling paints, but rather that it should point a way to possible integration of the technique with a slightly modified line of paint research.

Introduction

Since 1961 various proposals have been considered by the AEDU for the underwater cleaning and painting of R.N. ships' hulls by divers. The requirement to be able to do this is not pressing, but as bases around the world become limited, the need for a full service afloat is likely to arise.

The AEDU proposed in 1963 that a technique for hull cleaning should be developed but this was abandoned due to the danger that the removal of marine fouling underwater would damage the anti-fouling paint and so leave the hull unprotected against attachment of larvae and weed, and open to local corrosion.

It was proposed to use a team of underwater swimmers wearing a lightweight underwater breathing apparatus such as the R.N. Surface Demand Diving Equipment (SDDE), which enables a diver to swim with the minimum encumbrance and unlimited submerged duration. The SDDE is the recommended breathing apparatus for all Diver Ship Maintenance work.

Recent reports from various sources indicated that the hulls of merchant ships are being cleaned by divers as a matter of course, with no adverse effects. The technique is in use in Cardiff and Marseille.

Commercial Organisations

A visit was made by the author to Cardiff where the firm of " Underwater Welders and Repairers Ltd. " has started a regular routine of cleaning ships' hulls underwater. The firm is trying to extend this service to other ports in the U.K.

The system at present involves a large lorry mounted (600 cu. ft./min.) compressor which can be driven to any port, complete with a team of four divers and their hull cleaning tools.

These tools include an 18 in. diameter brush with nylon or wire bristles, which is fitted to a

pneumatic rotary tool supplied with air by low pressure hose from the compressor. The exhaust is led away to the surface by a second hose. Operation of the tools by the divers is simply a matter of turning on the air and guiding the tool over the fouled area. The action of the brush in the water produces its own " limpet force " suction onto the hull. This " limpet force " is due to the water moved by the bristles being radially displaced by centrifugal force and this creates an area of lower than ambient pressure in the centre of the brush. Little further information was gained at Cardiff except that all the ideas and tools originated from International Technical Services at Marseille who have been doing this work for more than six years. A visit was subsequently made to this Company on 25th-29th September 1966.

An expanded commercial organisation is proposed by International Technical Services which is to consist of two teams, each of four to six divers, based at all the major commercial ports throughout the world. Each pair of teams is to have its own launch and land based compressors with hull cleaning equipment as described later. At present divers are under training at Malta, Singapore, Newcastle (Australia), New Zealand and Cardiff. When sufficient divers are trained and established in their respective ports, the expanded service of hull cleaning will be available to merchant ships, enabling them to keep up a regular underwater maintenance routine wherever they are.

Initially, the only service will be hull cleaning, but investigation is continuing into the difficulties of painting, propeller changing, tail shaft changing and rudder repairs underwater, with a view to adding these techniques to the existing service. At present a total of about 600 ships a year have their hulls cleaned underwater at Marseille, the majority before dry docking; either at anchor, when the divers operate from a launch, or in dock prior to pumping out the water. The divers then operate from the dockside.

One of the most remarkable facts about this system is the low number of diver-hours required. Four trained divers can remove roughly 70% of the total fouling on a tanker of 40,000 t.d.w. in four hours (16 diver-hours). By comparison, it takes a total time of one week for 24 unskilled men to clean the hull of an aircraft carrier in dry dock, which is 720 man-hours assuming a six hour working day five day week. (In dry dock the amount of fouling removed is naturally almost 100%).

Figs. 1 and 2 show the problem graphically. Fig. 1 shows three curves, power-speed, under identical loaded conditions, of a 35,000 t.d.w. tanker. Curve A is at acceptance trials, showing that at maximum s.h.p. the vessel achieved 16¼ knots. Speed and power steadily decreased and just prior to its sixth annual dry docking, a sea trial was made which resulted in Curve B. The vessel was dry docked, cleaned, blasted down to bare metal and new protective coatings applied. Nine days later another sea trial was carried out which resulted in Curve C. (The same propeller was used on all trials, but it was cleaned only). It can be seen that the difference in s.h.p. to obtain 15 knots is remarkable.

Fig. 2 shows the drop in speed when a typical 17 knot turbine tanker is run at its service power between annual dry docking, together with an estimated curve, transposed into percentage increase of fuel consumption should an attempt to maintain the service speed be made throughout the year.

As a test after the development of underwater cleaning and experimental underwater painting, a ship, similar to that described in Fig. 2 was kept

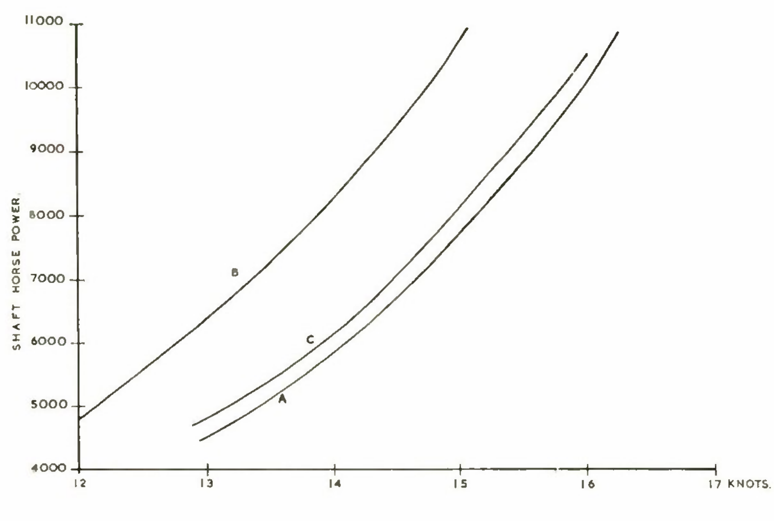


FIG. 1. Drop in performance of a 35,000 T.D.W. tanker (A and B) and improvement after dry docking (C).

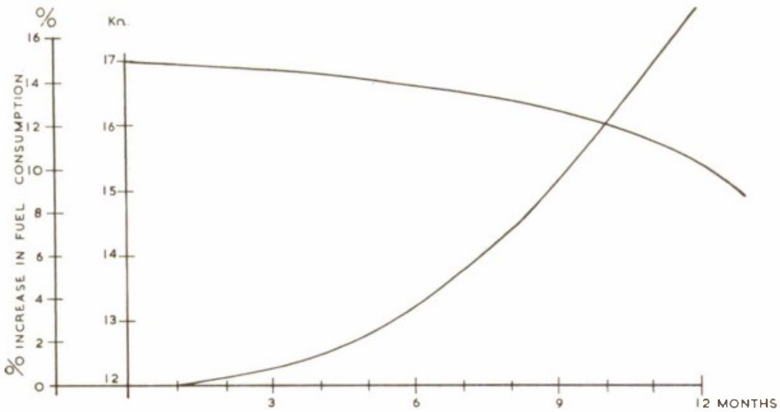


FIG. 2. Drop in speed and increase in fuel consumption of a 17 knot turbine driven tanker when run at service power between annual dry docking.

out of dock for 26 months and cleaned at seven monthly intervals by divers. It was also painted after cleaning once at 14 months. The results are indicated by Fig. 3. When the ship was drydocked after 26 months she was in a condition equal to that of a ship docked 12 months previously.

Hull Cleaning Equipment

Compressors

(a) Ingersoll Rand 600 cu.ft./min.—Land based.

(b) 600 cu. ft./min. compressor fitted into the launch and powered by the launch engine.

Air Supply

For the tools, high pressure air reduced to 65 p.s.i. and supplied *via* a reservoir directly. For the divers, reduced and supplied *via* the same reservoir to two filters and a separator and then to the divers' demand valves through ½ in. bore hose coiled on reels.

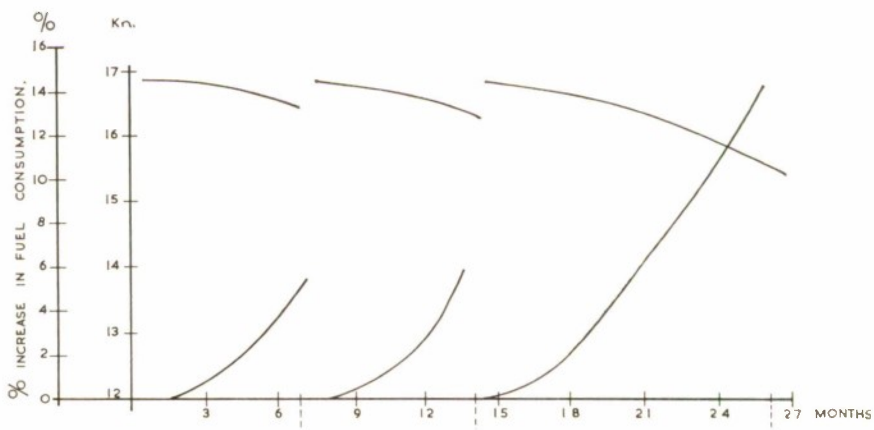
Pneumatic Tool

Four vane air motor consuming up to 70 cu. ft./min.—underwater speed after gearing down and loss due to water drag about 500 r.p.m. depending on how far the air control is opened. The motor and gearing is enclosed within a watertight alloy casing. Approximate cost £140.

Brushes

Various sizes from 9 in. to 18 in. diameter, wood or plastic backed, with tufts of wire, nylon or bristle for different states of hull. These are also used on propellers, the interiors of inlets and outlets and in other restricted spaces. Approximate cost £3 - £4 each.

FIG. 3. A tanker similar to Fig. 2 kept out of dock for 26 months with hull cleaning and painting by divers.



Underwater Painting

At Marseille, the application of paint underwater has progressed to the stage where paint can be applied to a large area, provided that the surface to be coated is in good condition. The method of application is by a rotary brush, using a power unit similar to the underwater cleaning tool but with the drive geared down so that the spindle revolves at about 50 r.p.m. Paint is supplied to the brush from a standard pressure paint pot, through a pressure tube into a spindle housing on the tool and then through the spindle to four nozzles embedded in the brush bristles. This system is considered efficient and a demonstration arranged on a steel plate at a depth of 7 ft. gave a good even coverage of anti-corrosion/anti-fouling paint over an area of 50 sq. ft. in five minutes.

This technique has not reached a suitable stage for general use on ships' hulls due to two factors:

(a) The tool, although effective, is too heavy and cumbersome in its present form and uses a rather "Heath Robinson" selection of gears.

(b) Painting can only be done on a good surface. The latter point means that shipowners will have to be convinced of the necessity for regular cleaning and painting in order to preserve a good surface for coating (*i.e.* no severe breakdown of the anti-corrosion coating). Many commercial ships have hulls which are very badly neglected, and in this state the owner cannot expect to have the hull cleaned by divers and then painted effectively. At the present time it is not possible for hulls to be cleaned down to bare metal and painted underwater.

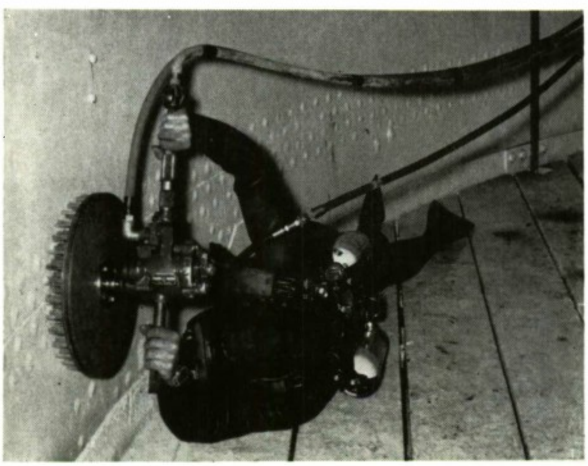


FIG. 4.

The Submerged Hull—Commercial v. Military Ships

The object of observing demonstrations of these techniques was to evaluate this type of system for use on R.N. ships and to determine the main differences between the operation on commercial ships and naval vessels.

Differences in	*Commercial Ships (Tankers in particular)*	*R.N. Ships (general)*
Hull Shape	Vertical sides to which marine fouling clings — the fairly flat bottom does not receive much light and unless laid up for a long period does not become heavily fouled.	"V" section, hence marine fouling occurs in larger quantities near the waterline and tapers off towards the keel.
Hull Fittings	None of importance.	Certain hull fittings, *i.e.* sonar domes, transducer windows and others will need to be cleared carefully or avoided.
Propellers	Minor damage is not of major importance	Some have delicate blade edges and profiles; careless use of tools must be avoided.
Seagoing Time	Almost continuous	Intermittent
Waterline	Regularly varies	Varies only occasionally within small limits.

Due to the above differences it will be seen that the R.N. ship is likely to have fouling over a larger percentage of submerged hull area than a commercial ship for a given length of sea-time in similar conditions. This statement requires qualification due to many other factors; notably, the increased likelihood of docking of a R.N. ship for other work and the superior anti-fouling paint used in H.M. dockyards, but it does however give a comparison.

Considerations for the Fleet

From the above it can be seen that value in terms of increased speed, lower fuel consumption and extended docking periods could be obtained for operational R.N. ships by cleaning the submerged hull from the waterline to a depth of about 10 ft. at regular intervals. Under normal peacetime con-

ditions the requirement to do this regularly between dockings may not exist, but if events imposed any restriction on docking then this system would be invaluable.

Using swimmers to clean the hulls of R.N. ships as a routine before they dry dock would be a valuable labour saving operation. The following advantages could be obtained:

(a) A reduction in time for hull cleaning

(b) A reduction in man power

(c) No mess on the dock floor as all waste would be floated away

(d) A dock which is almost immediately clear, allowing access to the hull for maintenance as soon as pumping out is completed.

(e) Shorter time in dock giving more dock availability

The technique of painting the whole submerged hull underwater is not considered to be sufficiently advanced at present for routine application on R.N. ships, but it has great potential. However, in limited application, benefit may be obtained by painting the waterline area to a depth of about 5 ft., at regular intervals between dockings. This would give continuous protection to the vulnerable splash-line area against the corrosion and fouling by green weed which often occurs there.

A device for painting small areas of hull underwater after Diver Ship Maintenance work is at present under development at the AEDU to meet an existing Staff Requirement.

Trials by the AEDU

Since the methods described were witnessed, the AEDU has been loaned a simple apparatus, which was recently produced in Holland, and which works on the same principle as that developed by International Technical Services. This tool was introduced to us independently by another firm interested in the technique. The photograph shows a demonstration of this apparatus in use by an AEDU diver wearing SDDE. One week of diving trials has been completed using six divers operating on a destroyer while she was de-equipping. The successful operation of this tool depends very much on the skill of the individual diver, but the overall result was good and tended to confirm the views expressed in this article.

The search for an underwater painting technique which started in the AEDU three or four years ago, originally met with little success, and enquiries had to be made as far afield as Liechtenstein for suitable painting media. However, since the almost simultaneous discovery in Europe and America of the underwater adhesive and setting properties of epoxy resin mixes, a number of firms, French and British, are offering versions of this compound. It was noticed at the Boat Show this year that one firm was featuring a gimmick for yachtsmen—"Epoxy Underwater Anti-fouling paint—apply it yourself and save docking costs". It is true, it can be done, but the mechanics of the task have a little way to go before *Ark Royal* or *Hermes* can be totally treated while afloat. The AEDU expects, before long, to contribute a diver's painting instrument which will bring that day nearer.

SYMPOSIUM ON THE USE OF PLUTONIUM AS A REACTOR FUEL

Sponsored by the International Atomic Energy Agency and held in Brussels 13th - 17th March, 1967

Reported by J. Edwards, B.Sc., A.C.G.I., Whit. Sch., R.N.S.S.
Professor of Nuclear Science and Technology Royal Naval College, Greenwich

Introduction

The growing confidence in the safety, economics and ability to build fast reactors—principally demonstrated by the UK, USA and USSR—plus the knowledge that plutonium is likely to be available in quantity for the European Community by 1975-1980, and in the UK and USA by the early 1970's, together with the well known pressure in all countries for increased power per head of population, and the undoubted limits that exist on future availability of U^{235}, prompted the International Atomic Energy Agency to organise the present Symposium. That this was a timely moment was demonstrated by the fact that 23 countries and three International Organisations were represented, by some 250 delegates, and nearly 60 papers presented. The problems of Plutonium utilisation are generally realised (although they appear to have different solutions, depending upon nationality), and range from the difficulties in carrying out accurate physics calculations due to the uncertainty of the Pu isotopes and their cross sections, the fabrication problems and associated health physics risks and costs, the burn-up capability and irradiation effects (in particular migration and gas release), the economics of various Pu cycles, the possibilities of ultimate competition between thermal and fast reactors for Pu, and the relative place each system should occupy in a national and world power programme, as well as national and international reprocessing problems conected with coping with future Pu fuelled systems. Most of these aspects were touched upon, even if not all were covered particularly adequately in the papers presented at the Symposium. Two papers which might have proved of considerable interest—those on performance and post irradiation checks on PuO_2-UO_2, and PuO_2-UO_2ZrO_2 fuels respectively, by Nuclear Materials and Equipment Corporation, Leechburg, Pennsylvania, were withdrawn before the Symposium started. A number of papers were read, but not available at the Symposium notably the Russian, Canadian, and one or two Belgian papers. In general the physics of the Pu systems were scantily dealt with, but metallurgical aspects were reasonably well covered.

The Conference was held at the Palais des Congres, Brussels, and organised in nine Sessions. Dr. Eklund, Director of the IAEA, formally opened the Conference. Visits were arranged through the local Travel Agency to nearby centres of nuclear interest, *viz.*, Mol, C.E.N., *etc.* This Conference, as is usually the case with IAEA sponsored meetings, was very well organised, and it is always a pity that discussion on individual papers appears to be generally so limited and formal on such occasions; in the case of a number of papers, questions or comments were either nil, or at most confined to one or two queries inviting, and getting, fairly terse answers. Possibly a dozen papers obtained a good question session and on these occasions, questions were stopped because of lack of time. The proceedings of the Symposium will appear in about September 1967.

Papers Read at Symposium

The papers read at the Symposium are given in the order presented below. Where comment is felt to be necessary—as perhaps provoked by the paper itself, or—on rare occasions—by the discussion, this is given. A set of abstracts of papers and the issued papers themselves are, however,

held by the Department of Nuclear Science and Technology at RNC Greenwich (IAEA ref. SM88), and it is not proposed to repeat all of such abstracts in this report.

SM88/8. Analysis of plutonium fuelled light water reactors. F. Dawson et al., Batelle-Northwest, U.S.A.

This deals with the physics and economic aspects of studies in hand by Batelle for the USAEC's Plutonium Recycle Programme, with particular reference to the PWR and BWR system as most likely candidates for Pu use before the fast reactor programme gets under way. The adequacy of the physics models used in predicting keff are assessed, and uncertainties due to Pu isotopes, fuel lifetime and fuel costs are evaluated. Light water moderated critical experiments using eight different Pu fuels were used as part of the evaluation.

An item of interest mentioned in the discussion was the Phoenix Fuel Programme, relating to a study of Pu fuels with high proportions of Pu^{240}. It is stated that this work might be of use in special purpose maritime reactors, or MTR type systems.

SM88/24. Physics of Plutonium Recycling in Thermal Reactors. G. G. Kinchin, A.E.E. Winfrith, U.K.

The author indicated in his opening remarks that UK opinion was still firmly on the use of Pu in fast reactors as being best for the U.K. situation, but the work reported on thermal systems was undertaken in order to obtain an appreciation of alternative programmes. The paper reviewed in some detail the reactor physics studies on Pu enrichment of AGR's, and recent work relevant to the recycling in SGHW's. The author appeared reasonably satisfied with the accuracy of the calculational methods evolved.

SM88/1 Physics of Plutonium fuelled thermal research and test reactors. C. Kelber. Argonne National Laboratory, U.S.A.

The use of Pu in high flux test or research reactors is bound to increase the flux available to research workers since the leakage per unit power in a Pu^{239} system exceeds that for U^{235} by 15-60%. The MTR in the U.S.A. was operated with a Pu fuel core in 1958 for a total (at 30 MW F.P) of 262 MWD and gave good results. Despite this, there has been no general use of Pu cores in test reactors, for reasons variously cited as—Pu is rare, it is difficult to handle, and it poses a hazard on release to the atmosphere much greater that that associated with uranium. The author analysed these aspects, and gave the results of an examination of three representative cores in terms of usefulness to experimenters requiring high flux. An interesting speaker, but a somewhat scanty paper which really only endorsed the MTR findings.

SM88/15. Methods of calculating UO2-PuO2-H20 lattices. L. Bindler et al., Belgo-Nucleaire

This paper was not available at the Symposium. The various computer codes used by Belgo-Nucleaire were briefly described, and the results of testing these methods on Hanford & Saxton Pu lattices were analysed. With certain modifications to constants etc., it was predicted that calculations on these lattices in thermal systems would yield an accuracy of $\pm 1\%$ for multiplication constant, $\pm 4\%$ for power distribution, $\pm 1\%$ for reactivity during irradiation, $\pm 20\%$ for reactivity coefficients and $\pm 10\%$ for reactor control. No questions were asked on this paper.

SM88/16. Plutonium assembly in the core of the BR-3/Vulcain E. DeMeulemeester et al., Belgo-Nucleaire.

This paper was issued in French and describes the work and calculations leading up to the introduction in the BR-3/Vulcain core of 19 vibro compacted rods and 18 pellet type rods containing Pu enriched natural UO_2. Power distributions over the transverse cross section of a rod, heat fluxes and temperature distribution were calculated. Irradiation has only just started.

SM 88/50. Experimental determination of the neutron characteristics of UO2-PuO2-H20 lattices. J. Debrue et al., Belgo-Nucleaire.

This paper was issued in French. It described experiments in the Venus zero energy test facility on a fuel assembly made up of 37-UO2-PuO2 pins with the object of refining mathematical models for calculating the performance of this assembly. Fission density distribution and the changing ratio of effective cross section for fission in the Pu^{239} and U^{235} were measured. Other critical experiments now being carried out were also described: these use 3 types of fuel *viz.* UO2-PuO2 with 3% U^{235} and 1% fissile Pu, and with 2% U^{235} and 2% fissile Pu, and UO2 with 4% U^{235}. The two UO2-PuO2 mixtures have different isotopic contents of Pu^{240}. A good deal of basic information was given in this paper.

SM 88/54. Dynamics of expanding Plutonium fuelled systems of Nuclear Power Plants. W. Frankowski. Institute of Nuclear Research, Warsaw, Poland.

This paper described a mathematical method, employing several sweeping assumptions, of analysing the plutonium investment, breeding, and economics of a large nuclear power producing system building up over a period of years.

SM 88/56 & SM 88/58

(i) *Investigation of ternary alloys Pu-Ce-Ni as a possible fuel for liquid metal core of fast reactors. T. S. Menshikova et al., U.S.S.R.*

(ii) *U-Pu based multicomponent alloys as fuel for fast reactors. G. S. Smotrizki et al., U.S.S.R.*

Only abstracts of these papers were available. Both were presented by N. T. Chobotarev, who confined his remarks to the metallurgical aspects of the alloys under consideration.

SM 88/34. Plutonium fuel design aspects for a large BWR. K. Uematsu et al., Atomic Fuel Corporation, Japan.

This paper analysed the physics and economic consequences of direct substitution of fissile Pu for U^{235} in an existing BWR fuel geometry in an existing BWR system. Whilst one admired the tenacity shown in the work involved, it appeared of use only to the Japanese who were obviously contemplating such a method of using any available Pu. If they were serious in this idea, it would appear that much more widespread economic studies are necessary.

SM 88/13. Manufacture of oxide fuels by vibration. H. Bairiot et al., Belgo-Nucleaire.

This appeared to be a good paper with excellent presentation. The author described and compared various techniques for fabricating plutonium fuels and discussed the advantages and disadvantages of each on the basis of experimental data. Also described was work on the development of essential supporting facilities for analysis, inspection and waste recovery.

SM 88/30. Fabrication of UO2-PuO2 and ThO2-PuO2 experimental fuel. A. T. Jeffs, R. Boucher et al., AEC Ltd., Chalk River, Canada.

This paper was not available at the Symposium. The author described the fabrication procedures used for 6 elements of mechanically mixed UO2-PuO2 plus two enriched UO2 reference elements. Two alternative routes were used to permit comparison of performance in test in pressurised water loop in the NRX reactor. These involved conventional hydrogen sintering at 1600°C and a low temperature route starting with hyper-stoichiometric mixed oxides and using Ar-10% H2 as the reducing atmosphere. Three elements containing mechanically mixed ThO2-PuO2 were fabricated by a conventional high temperature sintering route.

SM 88/28. The Plutonium fuel laboratory at Studsvik and its activities. G. Berggren et al., A. B. Atomenergi, Sweden.

This paper gave a straightforward description of the build-up, facilities, and lay-out of the Studsvik Active Central Laboratory.

SM 88/39. The manufacture of Pu fuelled fission product retaining coated particles for irradiation in the Dragon reactor experiment. G. W. Horsley et al., AEE, Winfrith.

Details were given of the fabrication route used to produce fuel for two elements of the Dragon reactor experiment. Results of the pre-irradiation test evaluation were given.

SM 88/3. The fabrication of Plutonium from highly irradiated reactor fuel. A. B. Shuck. Argonne National Laboratory, U.S.A.

This was the first paper to deal with quantities of Pu likely to be encountered in production work *viz.* multi-kilogram quantities. It contained a great deal of useful information, particularly on neutron and gamma dose rates to be expected in fabrication, and covered a range of plutonium isotopic compositions. Plutonium, containing from 10 to 50% of the higher Pu isotopes is scheduled for fabrication into substantial quantities of zero power reactor fuel elements from now until 1969, and will include some 215 kg in the 25 to 35% Pu^{240} range that is expected to contain 6-9% Pu^{241} and 1·0 to 1·2% Pu^{242}. The only doubts raised in questions concerned whether or not one could sustain such a highly efficient but very costly solvent extraction process as used at Argonne in order to eliminate the fission products in a full Pu fuel production process. It was thought that this would not be so, in which case remote handling and much more shielding would be necessary, using jacketed fuel techniques. It was also thought that remote fabrication would be necessary if the Pu^{241} concentration was greater than 7%.

SM 88/19. Fabrication of UO2-PuO2 fuels for fast reactors. H. Audriessen et al., Belgo-Nucleaire.

This paper is in French. It was well presented, with the aid of excellent slides, by J. Leblanc. The costs of fabricating mixed oxide fuels were analysed to guide C.E.N. to the mechanical mixing route rather than the co-precipitation route.

SM 88/51. Plutonium distribution and diffusion phenomena in UO2-PuO2 ceramics. R. Theisen and D. Vollath, Karlsrube.

This paper was not available until the end of the Symposium. The presentation gave a clear account of the metallographic, autoradiographic, X-ray diffraction, and electron microprobe analytical

techniques used in determining the relative amounts and distribution of the mixed oxides. The UO_2-PuO_2 pellets examined had been sintered for various periods from one to 30 hours at temperatures of 1400°C.

SM 88/44. Diffusion in mixed U-Pu oxides. R. Lindner et al., Euratom.

Self diffusion in nuclear fuels has been the subject of much investigation in recent years, since the behaviour of such fuels during fabrication at high temperatures, and during reactor operation is largely determined by self diffusion processes, mainly volume diffusion. The present paper dealt with results obtained in measurements on exactly stoichiometric reference material *viz.* 15% PuO_2-85% UO_2 pellets produced by co-precipitation, in order to discover the basic diffusion properties of the mixed oxide.

Thermal diffusion in UO2-PuO2 mixtures. W. Germany.

This was an additional paper and as such had no formal number, nor was it available at the meeting. An account was given of the technique of inducing a considerable temperature gradient in the test pellets of 2300°C at the top end of the 0·5 cm length and it was found that migration of PuO_2 in UO_2 had occurred towards the high temperature end due to thermal diffusion. In high centre temperature fuels at about 2600°C one could expect a substantial movement of the PuO_2 in some 10,000 hours.

SM 88/33. Some data derived from the fabrication of the first Rapsodie core, M. Ganivet et al., CEN, Cadarache, France.

The paper is in French. The fuel elements of the first Rapsodie core were fabricated during 1965/66 and some 3000 pins and 86 assemblies were produced from 70 kgm Pu. The Pu contained 10% Pu^{240} and 1% Pu^{241}. A full description, well illustrated, was given of the production line, and thoughts were put forward for the methods to be adopted for fabrication of fuel elements for the Phenix reactor, an operation some ten times larger. Consideration was also given to the economics of the production process.

SM 88/49. Production experience during "Sneak" platelet fabrication. W. Stoll. Karlsruhe, West Germany.

'Sneak' is a fast critical facility at Karlsruhe. 175 kgms of Pu, made into some 6000 plates (or a total of 55,000 square pellets) were made up. The pellets were UO_2-PuO_2 sintered mixes. Details were given of the production process, product control, accounting systems and chemical scrap recovery.

SM 88/35. Preparation of lower density UO2-PuO2 pellets. H. Akutsu et al., Atomic Fuel Corporation, Japan.

Two kgms of Pu are being used by the Japanese in the preparation of an irradiation experimental programme in the Enrico Fermi Fast Breeder Reactor as a first step in their programme to study stability against swelling. The fuel pellets are to be of PuO_2 (40%)-20% enriched UO_2 (60%) together with hollow pellets and vibratory compacted fuels, and are to be ready for irradiation Spring 1967. This date might be incorrect in view of the accident to the Fermi core! The fabrication processes and results of tests were described. Some very good electron microscope studies were shown.

SM 88/40. Fabrication of fast reactor fuel pins for test irradiations. T. Dippel et al., Karlsruhe, West Germany.

The fabrication of vibratory compacted UO_2-PuO_2 fuel pins was described, and problems of fuel preparation, material selection and control discussed.

SM 88/59. Compatibility of some types of Pu fuel with structural materials. V. G. Kusnetzova et al., U.S.S.R.

An abstract only was available at the meeting. The presentation dealt with Plutonium mono carbide and compatability with Mo, Ta, W and Niobium, and Uranium-plutonium alloys containing 10% titanium and 10% zirconium with niobium, molybdenum and stainless steel. Tungsten appeared best with the PuC, and niobium with the plutonium alloys.

SM 88/12. Effects of fabrication techniques on the behaviour of oxide fuels under irradiation. H. Andriessen. Belgo-Nucleaire.

This paper dealt with the irradiation experiments carried out to determine the influence on the uniformity of PuO_2 distribution in UO_2-PuO_2 fuel elements manufactured by different techniques, with a view to postulating optimum fabrication parameters. This was a well produced and well illustrated paper with many autoradiographs including excellent gamma-counting graphs of the relative distribution of fission products.

SM 88/38. High temperature irradiation experiments on plutonium coated particle fuel. P. Barr et al. OECD (Dragon).

This paper described the results of tests on samples of fuel (described in paper SM 88/39). Particular attention was paid to the measurement of release rates of fission products as well as to the possible release of Pu under the high temperature conditions of the Dragon reactor. Results were very encouraging.

SM 88/29. Irradiation behaviour of experimental fuel assemblies of UO2-PuO2 and ThO2-PuO2. A. Jeffs. AECL, Canada.

This paper was not available at the meeting. Mr. Jeffs described the results of detailed examination of U/Zr2 clad oxide fuel elements after irradiation in NRX. Six elements were of UO2-PuO2 (up to 1·39 wt % PuO2) and these were compared with two enriched UO2 elements after operation at a peak rating of 55 W/cm to an average burn-up of 1300 MWD/Te oxide. The other three elements were ThO2-PuO2 containing up to 1·93 wt % PuO2 and operating at ratings up to 68 W/cm to a maximum burn-up of 1230 MWD/Te oxide. The results reported included profilometer data, fission gas release, metallographic examination and Beta/Gamma and Alpha autoradiography. The latter of course gave the Pu distribution. A very good presentation and well illustrated.

SM 88/14. Irradiation of fuel elements in the BR-3 reactor. H. Baimot et al., Belgo-Nucleaire.

This paper is in French. An account was given of the examination of 12 fuel elements, fabricated by vibration and compacting, followed by swaging, after irradiation in the BR-3 PWR at 4820 hours at full power. These elements were natural uranium, enriched with 0·96% Pu, in the form of oxides.

SM 88/4. Electron microscopic studies of structural changes in high burn-up UC-PuC. J. Kittel et al., Argonne National Laboratory, U.S.A.

This paper gave an account of painstaking and laborious work in the application of electron microscopy to study the formation of fission gas bubbles and solid fission products in high burn-up specimens of vibratory compacted UC-20 wt % PuC powders.

SM 88/25. Irradiation experiments on plutonium fuels for fast reactors. B. Frost and E. Wait. AERE, Harwell.

Fuels in fast reactors should have as high a density as possible and achieve high burn-ups (greater than 5% heavy atoms) at high mass ratings. These requirements are generally much more onerous than for thermal reactor fuels. The factor which limits the life of fast reactor fuels is the production of considerable quantities of fission products which cause the fuel to swell. Considerable emphasis has thus been placed in U.K. over the past few years to study swelling and gas release behaviour of fuels, and the interaction between swelling fuels and restraining cans. This paper described the work done and conclusions drawn. It was a well presented paper, clearly illustrated and obviously backed up by much solid work and theory; it was recognised as such and received many questions from the audience.

SM 88/48. Breeder reactor fuel testing in a non-thermal neutron spectrum. L. Wilkinson. G.E.C. Vallecitas, U.S.A.

The paper presented a method whereby a simulated fast reactor power and consequent fission product and temperature distribution could be produced with filtered neutrons in a thermal test reactor. A cadmium filter is used to achieve the desired spectrum.

SM 88/57. PuO2 fuel elements for reactor BR5. I. G. Golovin, U.S.S.R.

An abstract only was available at the meeting. The BR5 reactor has been operational from 1958 to 1965 and the author described the fabrication techniques used in the manufacture of the PuO2 fuel for the second reload of the core. These were fairly conventional. Physical properties of PuO2 were presented together with results of work on compatibility of PuO2 with Nb, Mo, W, Ta, Ni, Fe, Co, Cu etc., and with Nak and Na.

Many questions were asked, but only two or three were concerned with the paper; most were directed at getting information on future work and projects, and achieved singularly little factual response. It was learnt that the core loading in mid 1965 used PuC elements clad in 18/8 Nickel chrome steel. Some doubt was raised here, however, since the author later referred to this loading as being of UC elements. UO2 fuel would be used as the first charge in the new fast reactor.

SM 88/46. Problems of adapting aqueous reprocessing plants to the requirements of fast reactors. T. Barendregt. Eurochemic. Mol.

This paper is in French. It dealt with the main problems arising in the use of aqueous reprocessing techniques (now generally in use for thermal reactor fuels) for plutonium fast reactor fuels, *viz.* high specific activity due to the high burn up of these fuels, the need to keep fissile material losses much lower than hitherto, and the increased hazards connected with handling solutions with high plutonium concentrations.

Investigations on the dissolution of PuO2, U.S.S.R.

This represented an additional contribution, not available as a paper, and was presented by Professor Reshetnikov. He described laboratory scale work on irradiated and unirradiated PuO2, PuO2 dispersed in Al, and mixed UO2/PuO2 in solid solution. The irradiated material came from fuel irradiated in BR5 to a total integrated flux of

$2{\cdot}2 \times 10^{22}$ n/cm^2 after three years in pile and one year cooling time. The optimum solution for dissolution of irradiated PuO2 was 10N HNO_3, 0·1 NHF and 0·05N A1. The irradiated specimens always appeared easier to dissolve than unirradiated specimens. UO2/17½% PuO2, prepared by two routes, *viz.*, mechanical mixing and chemical co-precipitation, were studied for dissolution rates in nitric acid. The specimens prepared by the co-precipitation route had the advantage that no HF was needed with the HNO3. Translation appeared difficult here but the speaker was good humoured throughout the questioning.

SM 88/20. Reprocessing of mixed dioxide fuels by fluorination. G. Camozzo et al. Belgo-Nucleaire.

A straightforward discussion of the relative merits of employing fluorine, chlorine monofluoride, chlorine trifluoride, and mixtures of these reagents in fuel regeneration. No valid conclusions were likely to be drawn from this work until about 1969.

SM 88/2. Reprocessing of reactor fuels by fluoride volatility and pyrochemical techniques. A. Jonke et al. Argonne National Laboratory, U.S.A.

This represented the fourth paper read by Mr. Kelber in the absence of the authors. The audience suffers enough by having to listen to the reading of prepared scripts (for the benefit of the translators), and to have a paper read second-hand somehow removes the last trace of life from the subject. This paper gave a brief account of two types of non aqueous processes under development at Argonne National Laboratory. The only statement of external interest made was that the growth rate of the U.S. Nuclear industry was such as to require the establishment of a new major fuel reprocessing plant by 1970.

SM 88/52. The Impact of Plutonium content of spent reactor fuel on a fluoride volatility reprocessing plant. A. Schneider et al. Allied Chem. Corpn., U.S.A.

This paper was available in limited quantity and is not held at RNC.

It gave useful isotopic compositions and content of fuel discharged from PWR's and BWR's, estimated as a function of burn-up, original uranium enrichment, initial plutonium content, and plutonium recycle mode. It then gave a conceptual design for a commercial reprocessing plant based on the fluoride volatility process. Aspects of criticality, shielding, waste disposal and effluent control were reviewed.

SM 88/37. The uses of plutonium fuel in pressure tube heavy water thermal reactors. R. Shindo et al. Japan Atomic Energy Research Institute.

The paper examined—in not too much detail—the use of plutonium in Japan's nuclear power requirements in five possible ways: as a direct substitution fuel in existing systems, in a breeder, in a cross over system, in a mixture with thorium, and in a burner reactor.

SM 88/11. Plutonium utilisation in boiling water power reactors. E. Evans et al. G.E.C., U.S.A.

The G.E.C. has of course the major interest in BWR's, and this paper showed clearly that the Company is taking the necessary R & D steps to ensure that widespread use of the power reactor plutonium, becoming available in the U.S.A. by the early 1970's, will be feasible in BWR designs.

The programme, in co-operation with the USAEC, and the Edison Electric Institute is largely aimed at capitalising on the existing knowledge of UO2 fuel and cladding fabrication techniques possessed by the firm, the existing physics and thermal design processes employed in BWR's and so on, but it defines many areas of necessary development and concludes that it is feasible to utilise effectively, plutonium in current BWR designs. Indeed the Company is obviously anxious that this should be so!

SM 88/9. Plutonium recycle in PWR's. R. J. Allio et al. Westinghouse, U.S.A.

This paper described G.E.C's principal competitor's approach to the same situation *viz.*, how to make the most effective use of any surplus Pu available *in PWR*'s. This is a fairly detailed paper and sets out a quite formidable R & D programme covering a large number of critical experiments and an extensive metallurgical programme. One aspect not mentioned, is that Westinghouse is contemplating supercritical water cooling of fast reactors as an insurance policy, and much loop work is going on.

SM 88/26. Influence of long term plutonium value changes on fuel cycle costs of plutonium fuelled reactors. H. Gruemm et al. Austria.

A paper devoted to the derivation of a mathematical method, embodying rather major assumptions, of estimating fuel cycle costs.

SM 88/7. Fabrication and irradiation factors influencing recycle economics. D. DeHalas. Batelle-Northwest, U.S.A.

A very good paper which summarised Batelle-Northwest's views on fuel performance, and effects of throughput on fabrication costs, based on a major irradiation programme, and on detailed

analyses of fabrication costs for both UO2 and UO2-PuO2 processes. Figures were shown to illustrate thermal conductivity of UO2 and UO2-PuO2 as a function of temperature, fission gas release rates as a function of temperature, and unit cost as a function of throughput.

SM 88/22. Economic effects of plutonium recycling in thermal reactors. H. Bairiot et al. Belgo-Nucleaire.

This paper is in French. It was estimated that by 1980, the European Community would have available some 67 tons of Pu, of which 35 tons would be fissionable Pu. M. Bairiot's conclusion was that it seemed likely to be economic to recycle plutonium in thermal reactor systems for a least one and possibly two decades. (But see the U.K. view in the paper 23 below).

SM 88/23. The commercial aspects of the recycling of plutonium. R. Kehoe and J. Williams. UKAEA. Risley.

This represented the one paper in the economics session which set out quite clearly and rationally the decisions which had to be taken (and the problems surrounding these decisions) by the major plutonium producing countries. Whilst the analysis was set essentially in the U.K. nuclear context, it had clear lessons for the other interested countries. Although one overheard remarks from European delegates afterwards, that the paper represented mere propaganda, it had a slightly sobering effect on the audience. It was probably as well that it was not read at the beginning of the Conference, since the conclusion was that, in the U.K. at least, plutonium should not be recycled but should be stockpiled to support the fast reactor building programme which would utilise the Pu most effectively. This conclusion was reached despite the interest rates to be paid out on the Pu stockpile value.

SM 88/32. Optimisation of fast reactors and the structure of power station programme. H. Baillot et al. C.E.A. France.

This paper is in French. The authors show how the price of plutonium, fabrication and reprocessing costs, load factor, maximum burn-up, and time spent by the fuel out of reactor, affect the optimum characteristics of the core and blanket. Results are given for a 250 MW(e) reactor, and tentative figures for a 1,000 MW(e) installation. The effects of variations in these parameters on specific fuel power and total regeneration rate are examined.

SM 88/17. Calculation of the cost of generating power in a 1,000 MW(e) fast reactor. W. Debay et al., Belgo-Nucleaire.

This paper was not available at the meeting. It describes the method of calculation, suitable for an IBM 360 computer, of the discounted cost of fuel cycles. The programme, by means of sub-routines, also has the ability to give costs, in dollars per kgm of fuel, of various specific items or processes of interest.

SM 88/41. Production cost parameter analysis for fast reactor fuel elements. K. Kummerer. Karlsruhe.

This paper sets out a mathematical model for the derivation of fuel fabrication costs for a fuel with 15 wt % PuO2, clad in stainless steel, using pelletised fuel fabrication techniques.

SM 88/36. Plutonium fuel development in Japan. Y. Imai. Atomic Fuel Corpn., Japan.

The Japanese AEC's present policy is to develop the thermal reactor system of D20 moderated, boiling H20 cooled reactor type, and the sodium cooled fast breeder system. An experimental fast breeder of 100 MW(th) is to be constructed in the early 1970's, using 30 a/o fissile PuO2-UO2 pellets clad in stainless steel, requiring 220 kgm Pu. The paper was very general in nature and mainly consisted of the plans for development work over the next few years.

SM 88/31. Towards a Plutonium market. M. Ronteix et al. C.E.A., France.

This paper is in French. Estimates of plutonium production in the world (exclusive of the U.S.S.R. block) up to 1980 are given (see also Paper 23). Pu requirements for the various fast reactor programmes are also given. The paper then discusses the possibility of a Pu price collapse after 1970 if Pu storage is adopted, and the effects of such a collapse followed by a price rise as fast breeders enter service. A discussion of various means of securing a " harmonious market " for Pu is given. The author could not see the practical application of the U.K. policy of storage of Pu outside the U.K. Other countries appeared to find it difficult to grasp the advanced extent of U.K. Fast reactor technology.

SM 88/10. Civilian uses and production of Pu in the U.S.A. D. Boyer et al. USAEC Divn. of Operations Analysis.

A very slim paper for such an interesting title ! It nevertheless gives a table of civilian requirements for Pu up to 1976 and another table of Pu available from civilian reactors up to 1980. These show that there is a substantial gap to be met for the next

eight years, and this will probably be filled by Pu from the U.S. Government production reactors and from the U.K. The author believed that in U.S.A. in particular, with individual power utilities, and poor buy back prices of Pu fixed by the U.S. Government, there was great incentive to recycle the Pu in thermal reactors.

SM 88/21. Economic effect on the Pu cycle of employing U^{235} in fast reactor start-up. M. Egleme. Belgo Nucleaire.

This paper is in French. It deals with a possible solution to the problem of not having enough Pu to get off to a large scale start with production fast reactors, and examines several possible U^{235}/Pu^{239} combinations and routes.

SM 88/18. Prospects for the use of Pu in reactors. P. Haubert et al. Belgo-Nucleaire.

This paper was not available at the meeting. It examined the problems of whether the plutonium available before fast reactor technology is established sufficiently to permit the building of such plants, should be stored, recycled in thermal reactors, or sold.

SM 88/53. Preliminary design of a PuO2-UO2 core for demonstration in the Enrico Fermi reactor. T. Doyle et al. Atomic Power Development Associates Inc. Detroit.

This paper was not available at the meeting. The presentation gave a factual description of the year old design of a core scheduled for criticality in 1970 to produce 430 MW(th). It is 48″ high × 36″ dia. cooled by sodium with inlet at 600°F and outlet at 900°F. The paper gave useful criteria for cladding stressing and has been requested separately.

SM 88/42. Prospects of Pu fuelled fast breeders. D. Gupta et al. *Karlsruhe.*

This paper was not available at the meeting. The presentation assessed the accumulated energy costs and the total natural uranium requirements up to the year 2000, for different nuclear energy growth curves and converter-breeder combinations, and discussed the prospects of Pu fuelled fast breeders in this context. It subsequently pushed the analysis out to the year 2020 *viz.* 53 years from now. This appears to ignore any possibility of a more efficient power producing plant (cf Fusion) emerging and must be regarded as a somewhat pessimistic analysis. A steam cooled fast reactor, as an intermediate measure (1975-80) was considered to have a strong case.

SM 88/47. Assessment and experimental investigation of plutonium potential in ENEL water reactors. A. Ariemma et al. Italy.

This paper sets out the R & D programme to be followed with EURATOM for 3½ years from mid 1966 in support of using plutonium enriched elements on a recycle basis in the water reactors of Italy.

SM 88/43. Fuel cycle economics of fast breeders with plutonium. D. Gupta et al. Karlsruhe.

A fairly detailed analysis of fuel cycle costs was presented in this paper, which came to the conclusion that fast breeders, using either PuO2 or PC fuels, showed substantial economic gains over any existing thermal system.

Conclusions

Although some of the comments above on several papers are slightly critical, this nevertheless remained a good, informative, and valuable Symposium to have attended. A certain amount of useful and detailed information was obtained, but more importantly a good overall grasp of the plutonium utilisation problems of the near and more distant future, both nationally and internationally, was achieved.

NAVAL ORDNANCE INSPECTION LABORATORY, CAERWENT—R.I.P.

W. F. Maber, B.Sc., F.R.I.C., R.N.S.S.

After more than a quarter of a century of service to the Navy, the Naval Ordnance Inspection Laboratory at Caerwent will close in 1967. This is an inevitable consequence of the closure of the Royal Naval Propellant Factory at Caerwent, within whose bounds N.O.I.L. is situated, and the streamlining of the three Defence Services into the Ministry of Defence. It is, nevertheless, a sad occasion for all employed at the laboratory, and for all in the Navy department to whom the laboratory has endeavoured, we hope and believe not unsuccessfully, to provide a service in its own fields of expertise.

The laboratory was first opened early in the second World War, as the inspection laboratory for the newly opened R.N.P.F., built to supplement the original Naval propellant factory, R.N.C.F. at Holton Heath. After the war, in 1947, R.N.C.F. closed, all Naval propellant production being concentrated at Caerwent, and N.O.I.L. Holton Heath also closed, the old inspection laboratory buildings there becoming the nucleus for A.M.L., and N.O.I.L. functions being transferred to Caerwent.

Since 1947 N.O.I.L. Caerwent has been responsible for acceptance inspection and surveillance during Service life of Naval propellants and explosives and of a large range of materials used in association with them, for advice to the Naval departments on questions connected with propellants and explosives and, in association with the design and research establishments, for investigations of failures and malfunctions in Naval weapons. A full account of this work is given in *J.R.N.S.S.*, **9**, 6 (November 1954).

With the reduction in conventional armaments which has developed since 1946 it became doubtful whether the retention of two propellant factories, one Naval and one Army, was justified. After a committee of investigation and consideration of its findings a decision was announced in April 1965 that R.N.P.F. Caerwent would close, production being run down gradually over a period of some 18 months, with final shut down, after dismantling and decontamination, in about three years. All Naval production previously carried out at R.N.P.F. would be transferred to R.O.F. Bishopton.

It was obvious that N.O.I.L. could not continue to function as a separate unit at Caerwent without the support of factory services, mains supplies, police protection, *etc*. The possibility of continuing elsewhere was exhaustively considered, possibly in association with the Naval Proof Yard, which had to move from its site in Woolwich Arsenal. At this time, however, the co-ordination of departmental services within the Ministry of Defence was being actively pursued and, after investigation, the Defence Inspection Committee recommended that the work of N.O.I.L. should be handed over to Director of Chemical Inspection, Army Department. The Board of Admiralty approved this recommendation.

Despite considerable disappointment at this decision, implementation has been proceeding actively over the past nine months or so and, with cessation of production in R.N.P.F. towards the end of last year, has gained momentum towards completion by about June of this year.

Most of the work formerly carried out by N.O.I.L. has been dispersed among the various D.C.I. laboratories, *e.g.* propellants to Bishopton, fabrics and felts to Chorley, various miscellaneous materials to Woolwich. The main exception is the Closed Vessel testing of propellants which, because of N.O.I.L. expertise and the lack of an inspection Closed Vessel unit at Bishopton, will remain under Naval inspectorate control. In this instance, all Closed Vessel testing on behalf of the Naval and Army inspectorates will be concentrated in one unit at Bishopton, under the Naval inspectorate, but staffed by scientific staff seconded from D.C.I. The final delay in closing N.O.I.L. arises from delay in completion of the new Closed Vessel testing facility at Bishopton.

The scientific staff of N.O.I.L. have been, or are being, dispersed mainly to various D.C.I. laboratories, but a few, for Service or personal reasons, remain within R.N.S.S. establishments. At the end of the day the Naval Ordnance Inspectorate at Bath will be left with a scientific cell of two officers (Dr. T. W. Wight and the writer) who will be responsible for advice and for liaison with D.C.I. and with the design and research establishments.

Speaking for all the staff at N.O.I.L., we would like to put on record our deep appreciation for the sympathy and understanding with which the D.C.I. (Mr. H. Hollis) and A.D.C.I.(E) (Mr. S. Garlick) have approached the problems of integrating N.O.I.L. staff into their organisation. Mainly because of their co-operation we have been able to offer appointments to all our scientific staff in localities to which they were willing to go even if, understandably, they were not, in all cases, enthusiastic. This has meant, in particular, expanding somewhat the D.C.I. establishment at Glascoed, which, being only 15 miles from Caerwent and the only D.C.I. laboratory in the locality, offered the only practicable opportunity of continued employment for some of our staff.

We would also like to thank Capt. W. R. J. Redman who was the Chief Inspector of Naval Ordnance when the future of N.O.I.L. was under discussion, for the strenuous, though unavailing, efforts he made to keep the laboratory in existence.

For the future the Naval Weapons department will rely on D.C.I. for laboratory support in inspection work and on D.C.I. and the research departments for any investigational work that may be thought necessary. In the former case there should be no loss in efficiency and there could well be some economy, as D.C.I. is geared to undertake inspection on a much wider and more specialised scale than N.O.I.L. could ever hope to achieve. In the latter case, however, because of the dispersal of their specialists into the different and sometimes widely separated laboratories of the comparatively large D.C.I. organisation and the lack of staff and work overload in the research establishments, there will inevitably be some falling off in the service available to Naval inspection staff in the field.

The scientific cell at Headquarters, Bath, by personal contacts and informal discussions, and the D.C.I. organisation by maximum co-operation, will endeavour to reduce this loss in scientific support to a minimum. However, the peculiar advantage which has been enjoyed by N.O.I.L. of having a small group of experts working in close collaboration with each other and closely and personally associated with Naval staff in the field and at H.Q. on the one hand and with the design and research establishments on the other, must be lost, together with the personal service of help and advice which we have been able to build up over the years.

In conclusion, speaking for Dr. Wight and myself, who have had the responsibility of organising the work of N.O.I.L., and now of arranging its dispersal, we would like to express our sincere thanks and appreciation for the wholehearted support and co-operation we have received from the staff, particularly in recent months, since the impending closure was announced, during which time morale has remained remarkably high. We would like to wish all who have left N.O.I.L. every success and happiness in their new spheres of activity, wherever these may be. If we may be permitted to single out a few names without inviting invidious comparisons we may mention John Townend and John England, now at A.M.L.; Stan Hooper and Leslie Kingdon who will be stationed at Messrs. I.M.I. Summerfield for D.C.I.; E. E. Stephens (Steve) now at D.C.I. Woolwich; Enid Baker and Winnie Jones both, because of removal regulations relating to married women, transferred to D.C.I. Glascoed; Frank Tizzard and John Batt now with D.C.I. at Burghfield; Terry O'Neill who, after about two years at I.M.I. Summerfield, is trying his hand at statistical work, initially with Mat. 1 Bath; and Bob Lawrence and Lionel Terrell who will both be retiring from Caerwent being over 60 years of age.


Major Canadian radio communication systems
LEGEND
1 - TRANS-CANADA TELEPHONE SYSTEM MICROWAVE
2 - CN/CP TRANSCONTINENTAL MICROWAVE
3 - N.B. TELEPHONE/M.T. & T. MICROWAVE
4 - BELL TELEPHONE SCATTER
5 - QNS & LR MICROWAVE
6 - CN MICROWAVE
7 - QUEBEC HYDRO MICROWAVE
8 - QUEBEC TELEPHONE MICROWAVE
9 - ONTARIO NORTHLAND COMMUNICATIONS MICROWAVE
10 - MANITOBA TELEPHONE SYSTEM MICROWAVE
11 - MANITOBA TELEPHONE SCATTER SYSTEM
12 - SASKATCHEWAN GOVERNMENT TELEPHONES MICROWAVE
13 - ALBERTA GOVERNMENT TELEPHONES MICROWAVE
14 - CN SCATTER
15 - PACIFIC GREAT EASTERN RAILWAY MICROWAVE
16 - BRITISH COLUMBIA TELEPHONE MICROWAVE
17 - BRITISH COLUMBIA TELEPHONE SCATTER
18 - AGT/SGT SCATTER
DEW LINE
MID-CANADA LINE
POLE VAULT SCATTER
ADCOM II MICROWAVE
TELEPHONE COMPANY SYSTEMS
RAILWAY & UTILITY COMPANY SYSTEMS
DEPT. OF TRANSPORT Wx FACSIMILE SYSTEMS
CANADA
ST. JOHN'S
SYDNEY
HALIFAX
GOOSE BAY
SEPT ILES
QUEBEC CITY
MONTREAL
BAIE-COMEAU
KNOB LAKE
OTTAWA
TORONTO
BUFFALO
NORTH BAY
WINDSOR
FROBISHER BAY
CAPE DYER
THULE
RESOLUTE BAY
CAMBRIDGE BAY
SASKATOON
REGINA
EDMONTON
CALGARY
HAY RIVER
DAWSON
WHITEHORSE
KAMLOOPS
VANCOUVER
SEATTLE
PR. GEORGE
FAIRBANKS
ANCHORAGE

ARCTIC COMMUNICATIONS

Frank T. Davies

Chief Superintendent,
Defence Research Telecommunications Establishment

Communications in the Arctic do not depend as critically on climate as do most other phases of living and travel in the north. Installation costs however are high for all activities and construction must be done during the short northern summer. The main factor in communications in the Arctic and most of Canada is economic—the high costs of reliable high capacity systems in a large sparsely populated area. Such have been installed for reasons of national defence along and to the radar defence lines.

The most economical communications system is that based on HF via the ionosphere which, over the Arctic and most of Canada, is much more subject to disturbance and consequent HF blackout than over any other large country. This is due to the displacement of the geomagnetic axis towards North America which permits particle energy of solar storms to penetrate the ionosphere over most of Canada to an extent which occurs on the Asiatic quadrant only in very high geographic latitude. The equivalent condition in the Antarctic mainly affects oceanic areas.

Studies of the ionosphere have therefore continued as a major effort in radio science in Canada over the past two solar sunspot cycles. Basic data have been obtained from ionosondes at several sites; by monitor of many oblique incidence HF circuits across Canada and the north Atlantic; from riometer stations; and more recently from high altitude experiments in balloons, rockets, and satellites.

A HF prediction service for latitudes north of 35°N. has been developed by DRTE and gradually improved with time. This has some 85% accuracy when used as a guide to average conditions in the ionosphere but is very inadequate for disturbed conditions which persist at times for several days.

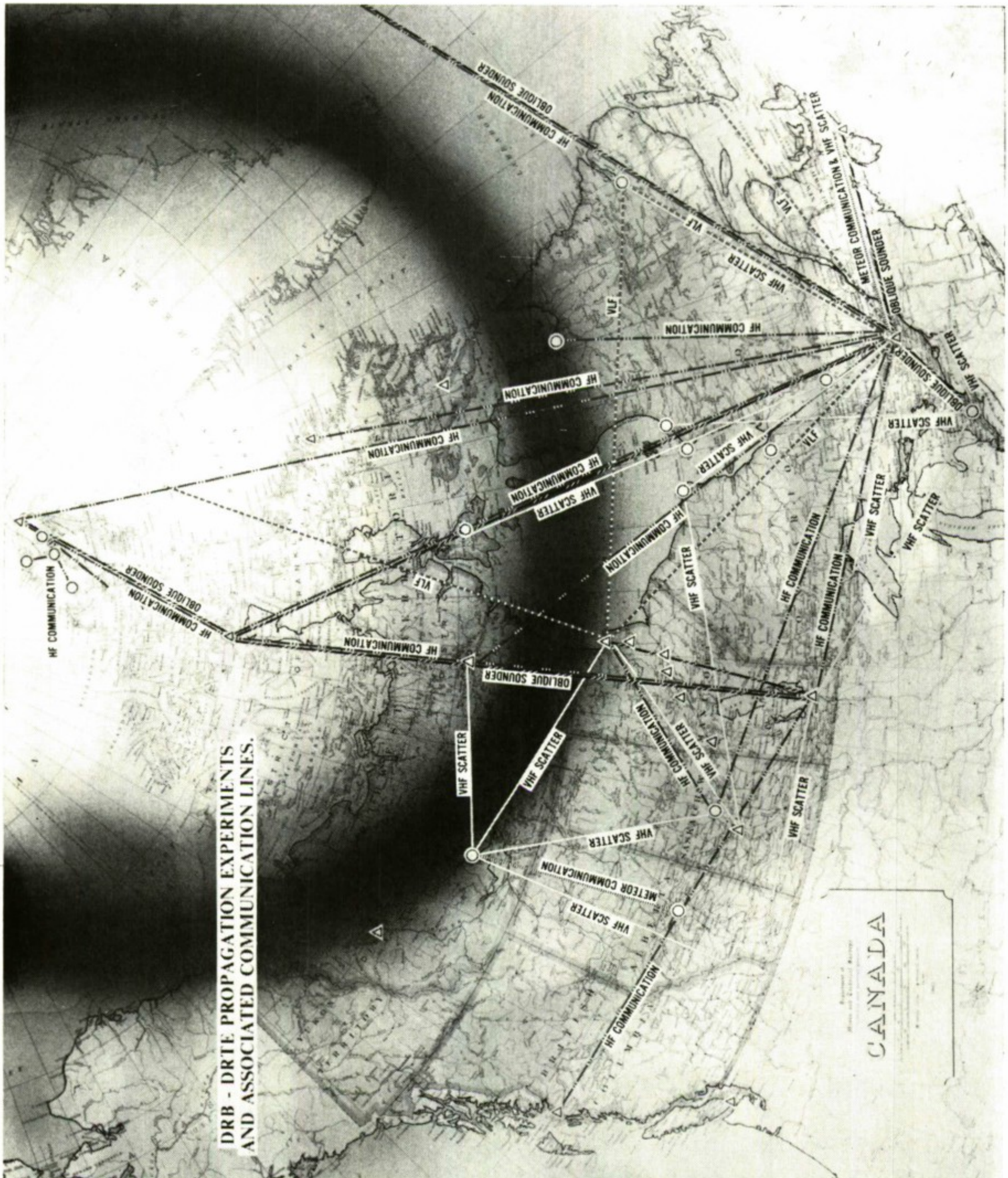
History

Radio communications in the Arctic began after WWI with HF radio telegraph in the Yukon and NWT installed by Royal Canadian Corps of Signals. This was expanded in the following decades and six broadcast stations were set up by the Corps at Arctic sites just after WWII. This system is now operated by the Department of Transport. MF stations were built about 1930 by the then Department of Marine, now the Department of Transport, to cover the area of the Hudson Strait and Hudson Bay shipping route after completion of the Hudson Bay Railway to Churchill. Continuous wire telegraph and telephone service is available to the termini of northern railways which now include Knob Lake, Que., and Pine Point on Great Slave Lake, as well as Churchill. A very important HF radio broadcast service to isolated posts commenced in the 1920's from KDKA, Pittsburgh. This was augmented later by CBC broadcasts on a high power MF station from Watrous, Sask, and later by HF broadcasts. These were and are much appreciated by residents of numerous isolated communities in Canada as well as the Arctic.

The Hudson's Bay Company commenced using HF in 1934 and five stations were operative by 1936. To-day some 75 HF stations serve a wide net of isolated posts and many have a two-way radio telephone facility. HF is also the primary communications medium of civil and military aircraft in the north. The range 2 to 6 Mc/s is the most useful for economical communication between Arctic sites because only two frequencies within this range are necessary for any specific circuit in order to communicate night and day. HF circuits are more reliable when they cross the auroral zone almost normally. Circuits along this zone often suffer outages due to absorption even during ionospherically quiet periods.

HF Radiotelephone Services are being steadily extended northward by provincial telephone companies and by Bell Telephone Company of Canada. The net based on Alma and Sept Iles, Que., and Goose Bay Labrador, now serves many communities in northern Quebec, Labrador, Baffin Island, and also Resolute. Another net extends from Churchill north. These are public services on a toll basis and Eskimos are now becoming users. Single side band techniques, noise suppressors, and automatic regulators are being used to increase

This paper was presented at the C.D.S.O. meeting in Canada 1966.


DRB - DRTE PROPAGATION EXPERIMENTS
AND ASSOCIATED COMMUNICATION LINES.
CANADA
HF COMMUNICATION
OBLIQUE SOUNDER
VHF SCATTER
VLF
METEOR COMMUNICATION
METEOR COMMUNICATION & VHF SCATTER

efficiency. Frequency predictions by DRTE were asked for and used in the Quebec to Arctic HF net.

An HF Communications net was set up soon after WWII to link the US/CAN Joint Arctic Weather Stations at Resolute, Mould Bay, Isaachson, Eureka and Alert. This net now has two-way radio telephone on single side band. A back up LF link between Resolute and the weather centre at Edmonton, although of low capacity, is more dependable than the usual HF link at times of increased ionospheric absorption. DRB annual expeditions to Northern Ellesmere Island since 1956 have in more recent years used light weight HF trail sets which have proven very effective in linking with the joint weather stations and with the two DRB expedition bases at Lake Hazen and Tanquerary Fjord in Northern Ellesmere Island.

Radio Relay on Microwave has been used over considerable distances on circuits to and along the radar defence lines. Small local nets have been installed by lumber and other commercial companies in Canadian mountainous western terrain.

Ionospheric VHF Scatter and Tropospheric UHF Scatter links have been used in connection with the radar links. Both are highly reliable and the latter has high capacity up to ranges of between 200 and 600 miles. The former has much longer range but is subject to about one per cent outage due to polar blackout. Its capacity is limited to between one and four teletype channels.

LF Systems are, like most systems except HF, expensive to install and maintain. The operational cost can be greatly decreased if service at a low information rate is accepted. Proper attention to the type and matching of the transmitting antenna allows of much lower power consumption than is usually aplied. The greater part of the power in LF transmitters generally goes into the ground.

VLF Systems. These vastly expensive installations are naturally few in number. They give world wide reliable communications at a low information rate. The development in recent years of reliable phase and frequency stabilization of VLF transmissions at a cost which is very low in comparison with the existing investment, can provide an accurate navigation aid to ships or aircraft almost anywhere on the globe. US and UK are actively developing these systems. Tests across the Atlantic have given an accuracy of ± 3 miles and ± 1 mile is expected on the final system. DRTE has monitored several VLF circuits during the past three years at the request of RAE/UK.

VHF — Meteor Burst System. This was developed by DRTE on 48 Mc/s originally and successfully tested between Ottawa and Halifax. Subsequent tests in the north between Edmonton and Yellowknife, NWT, showed outages due to polar cap blackout. These seriously decreased the value of this system. It was therefore redesigned on 104 Mc/s and tested for eighteen months between Ottawa and Goose Bay, Labrador with excellent reliability. Only seven hours outage occurred during this eighteen months test. The duty cycle must be short because of the high ionization density needed in a meteor-trail in order to reflect 104 Mc/s. Hence this system hasn't the capacity for large volume traffic. It has high promise for long distance emergency circuits where short messages must be sent with minimum delay. Each message is sent on a single meteor-trail. These occur so frequently in the required orientation that it is rare for an interval of five minutes to elapse between messages. Usually the interval is less than two minutes. A simulation of aircraft control was made from Ottawa interrogating aircraft instruments at Goose Bay. Automatic return of position, course, altitude, *etc*., data was received without operator attention. It is in aircraft control that this system might be most usefully applied.

HF Channel Sampler. This is a device developed by DRTE and now undergoing test by RCAF long distance patrol a/c. It depends on channel sampling between base and a/c to select the optimum frequency among those permitted. This is done automatically and so is a great aid to the a/c operator. The greatest value of this system is for flights in high latitudes where ionospheric conditions are frequently variable and operator experience is of little value. Its use in middle latitudes is only necessary when very intense ionospheric storms extend well south. Such conditions occur more often near the maximum of the solar sunspot cycle which can next be expected in 1967-1971. The regular HF prediction service is adequate for most of the time in middle or southerly latitudes. The airborne unit weighs 30lbs in a compact cubic foot. It is probable that production units when available will cost about $5000.

Satellite Communications Facility. This has been recently built at DRTE to examine propagation in the Gc/s range, particularly the frequencies (8-15 Gc/s) above those now being used. Although not an item in Arctic Communications research, the possibility exists of using satellite repeaters for multiple access at many points in Canada, perhaps in some Arctic centres. Satellite communications may replace most other long distance high capacity radio systems within the next decade but HF will almost certainly continue to be the medium of communications between isolated Arctic communities.

THE EXPLOSIVES RESEARCH AND DEVELOPMENT ESTABLISHMENT

R. L. Williams, M.A., D.Phil., D.Sc.
Superintendent, Materials Research I

G. H. S. Young, Ph.D., D.I.C.
Principal Superintendent (Development)

The Explosives Research and Development Establishment is situated in the River Lea valley some 13 miles north-east of Central London, adjacent to the well-known Waltham Abbey, which was founded in 1060. It is uncertain when gunpowder manufacture was first undertaken in this district, but there has been a long tradition of work on explosives in the neighbourhood, as is evidenced by the tombstones in the Abbey churchyard where victims of several early accidents are interred.

There is little doubt that gunpowder was made in Waltham Abbey about the time of the Armada, but very few records exist of the early days. This manufacture was in private hands and there were other important powder mills, notably at Faversham, Kent, by late Stuart times.

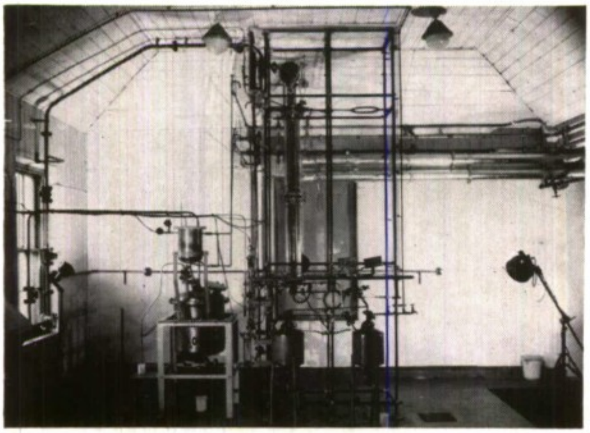
In 1787 there were complaints about the serviceability of black powder supplied to the Navy and after an enquiry, followed by firing trials conducted under the Board of Ordnance, it was established that Waltham Abbey powder was superior. It was recommended that the Powder Mills be purchased by the Government and they were taken over just in time for the Napoleonic Wars. It is probable that the gunpowder used at Trafalgar was made at Waltham Abbey. The first Superintendent was Sir William Congreve, who was succeeded in 1816 by his son who had already obtained a high reputation as a designer of rockets filled with black powder. These rockets were further developed and extensively used by both the Royal Navy and the Army until about the time of the Crimean War, when improvements in gun design caused them to become obsolete.

In this period many new powder buildings were erected at Waltham Abbey, some of which still survive, and black powder manufacture continued on a substantial scale. The manufacture of nitrocotton was undertaken in 1872, under the direction of Sir Frederick Abel and, following the work of Alfred Nobel, smokeless powder (or 'cordite') was made by about 1880. This manufacture necessitated the purchase of additional land in 1885, and the erection of new plants. There were several disastrous explosions, especially in the manufacture of nitroglycerine, and there were several Courts of Inquiry whose reports are still available in the Public Records Office. Present day segregation of explosives buildings and separating them by mounds dates from about this period. In 1909, under Sir Frederick Nathan, who was then Superintendent, a new stabilisation method in the manufacture of guncotton was worked out and this is essentially the process still in use to-day. The production of tetryl was commenced in 1912.

The heyday of the Royal Gunpowder Factory was in the 1914-18 war, when the South Site was considerably expanded and large quantities of Mark I cordite were manufactured. Some gunpowder was also produced as well as picric acid and guncotton.

In the inter-war years the factory ran down, but was reactivated in the 1930's and manufactured the Land Service cordite W (for Waltham), the Naval cordite production having, by this time, been taken over by Royal Naval Cordite Factory, Holton Heath. A plant for the manufacture of TNT was also brought into use and just prior to World War II an experimental plant for the manu-

facture of RDX, a new high explosive, was set up in collaboration with the Research Department, Woolwich. After the outbreak of war the factory continued in full production, employing some 6,000 people, until 1942 when it was succeeded by the new plants at Royal Naval Propellant Factory,



Plant for drying nitric esters to very low water content—this plant is operated remotely

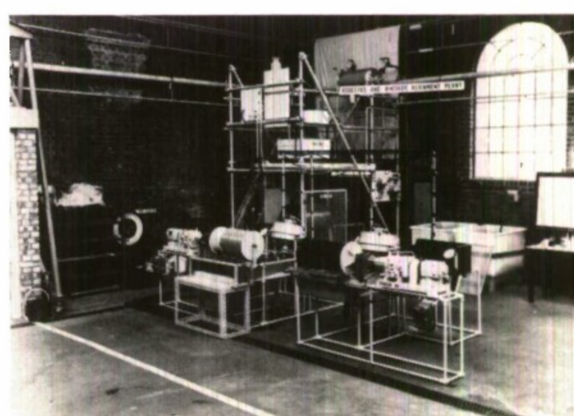
Caerwent, Royal Ordnance Factories Bishopton, Ranskill, Bridgwater and I.C.I. plants in Scotland. During this period its main claim to fame was the development of WM (Waltham Modified) cordite, and the first production of the Land Service flashless gun propellant cordite N.

There was a close association between the Royal Gunpowder Factory and the Royal Arsenal at Woolwich and the Naval Dockyards at Deptford and Chatham and with the adjacent Royal Small Arms Factory at Enfield. At one time the Metals Division of I.C.I. also had a small factory for filling rifle ammunition on the South Site. In the later part of the war, much experimental manufacture was undertaken for the Armament Research Department, and the conversion to an R. & D. Establishment in 1945 was a logical step.

The Factory was by then partly derelict, although it suffered very little damage by bombing during the war; there were only two chemical laboratories, one on each site. The first task was therefore to convert some existing processing buildings into laboratories and offices and to construct roads in the Establishment where most of the internal transport had been by barge on the numerous canals, or by narrow gauge railway. Substantial site clearance of plantations of willow and elder, previously used for charcoal manufacture, was also involved. New special purpose buildings have now been constructed for laboratory and pilot plant operations and the most recent of these have been a new Library and Lecture Theatre, a combined office and laboratory building for chemical engineering research and a new remotely controlled small scale plant for research and development work on composite high explosives.

Generally, research activities and laboratory investigations are concentrated on the North Site, whereas the pilot plant operation and work on propellants and explosives, other than on the laboratory scale, is conducted on the South Site.

Immediately after World War II, the main work of the Explosives Research and Development Establishment, as it then became, was concerned with liquid propellants, with the development of flashless gun propellants and research and development on plastic propellant, which had been introduced into the Service in the later part of the war. Another very important activity was to investigate methods for the synthesis of nitroguanidine (picrite), as this material was imported and it was desired to have an indigenous source of supply. In the early 1950's interest in liquid propellants began to wane, and the main centre of activity was transferred to the Rocket Propulsion Establishment at Westcott. Interest in gun propellant also diminished and the work on processes for the manufacture of nitroguanidine ceased although, by that time, a plant utilising the E.R.D.E. process was in course of erection at R.O.F. Bishopton. The main interest in the solid propellant field now centred on rocket applications and the work on the development of plastic propellants was extended, and facilities for the large scale manufacture of these propellants were established at R.O.F. Bridgwater based on the work carried out at



Experimental plant for alignment of whiskers and asbestos fibres.

E.R.D.E. At this time also, new facilities were brought into use for the manufacture of cast double base propellants and the plant for manufacture of extruded cordite, which had remained

at the Royal Arsenal, Woolwich, was transferred to the South Site. The Establishment was thus in a position to undertake research and development on any type of solid propellant, with particular emphasis on rocket applications.

In 1956 it was decided to establish a Materials Laboratory on the North Site at E.R.D.E.—this Laboratory being mainly concerned with the application of plastics to military stores. For example, one major activity at the time was the development of nylon driving bands for shells. Recently this work has been further extended by the creation of a group to investigate the properties of high strength materials, mainly ceramic, commonly known as whiskers.

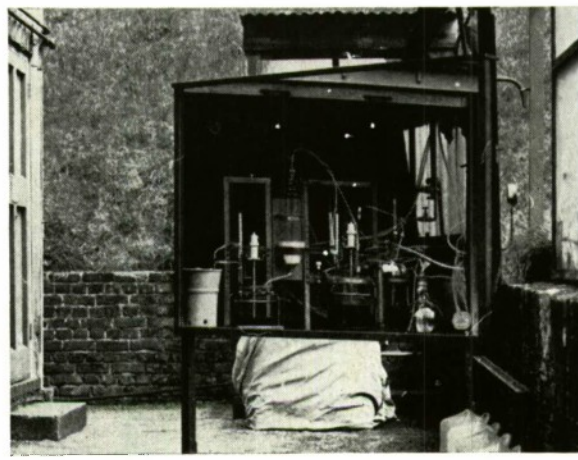
At present the Establishment is responsible for research and development of all types of military explosives and propellants, covering the requirement of all three Services. There are currently seven groups, each headed by a Superintendent. Two of these are concerned with research and development on solid propellants, one concerned with high explosives and methods of testing sensitiveness to impact, friction and the like, and two groups are concerned with non-metallic materials for any type of Service application. The two remaining are essentially service groups—the first deals with chemical and physical analysis, as required by any of the other groups and also acts in an advisory capacity on questions of compatibility with the Service Departments—laboratory scale organic preparations are also undertaken by this group. The second group deals with chemical engineering and their function is to scale-up laboratory processes and to provide pilot-scale quantities of hazardous chemicals, such as nitric esters, which may be required by the propellants or explosives groups. The total strength of E.R.D.E. is about 70 Scientific Officer grades, supported by some 110 Experimental Officer staff; most are chemists, but there are a few chemical engineers, physicists, and mechanical engineers. The present organisation is:

Director: Dr. L. J. Bellamy

Principal Superintendent (Development) Dr. G. H. S. Young

Individual Merit "B" Post	Mr. G. K. Adams
Superintendents	
Explosives:	Mr. E. G. Whitbread
Propellants 1:	Dr. W. G. Williams
Propellants 2:	Mr. P. R. Freeman
Materials 1:	Dr. R. L. Williams
Materials 2:	Mr. J. E. Gordon
Analysis and Ingredients:	Dr. I. Dunstan
Chemical Engineering:	Mr. R. G. Ross

The traditional propellant work of E.R.D.E., and its predecessors, is carried on in Propellants 1 Branch, which is largely concerned with colloidal propellants based on nitroglycerine and nitrocellulose. The various modifications of this propellant are manufactured by solvent, and solventless, extrusion, as well as by casting and a considerable variety of shapes and sizes is produced. These are used in small arms, mortars, guns, rockets and power cartridges. A recent development has been the design of a new cartridge for a Rocket Ejection Seat designed by Martin-Baker.

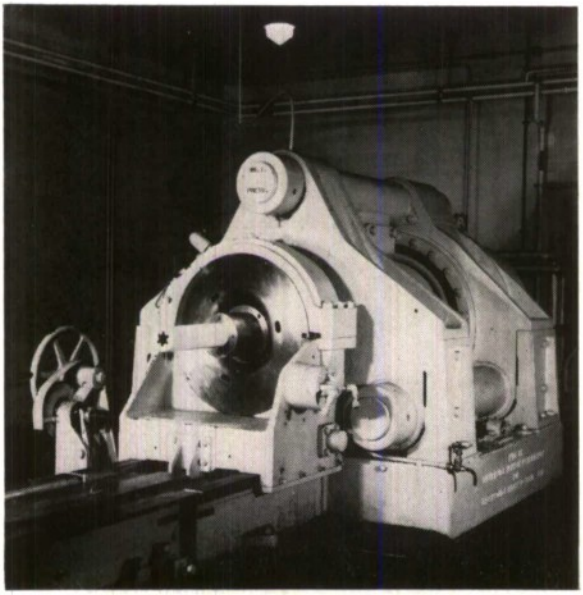


Glass plant for manufacture of hazardous chemicals.
This plant is operated remotely and is viewed from a concrete observation room by a 45° mirror.
This photograph shows the view seen in the mirror—the plant is housed in the building on the left.

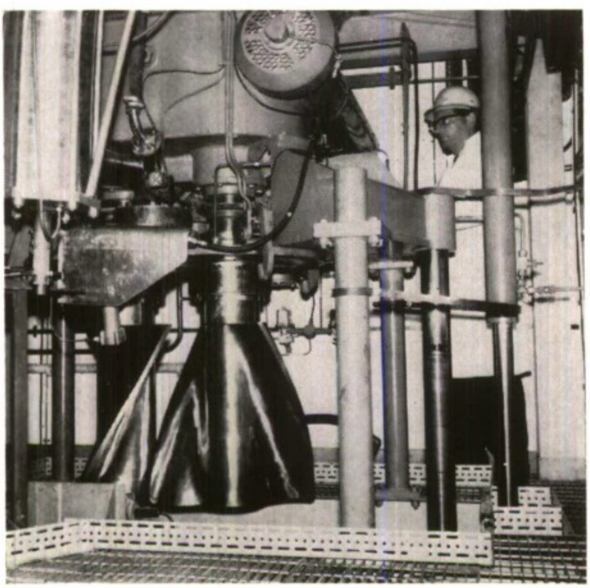
There is increasing interest in the reduction of smoke and flash from rocket motors and, in addition to work on propellant compositions and inhibitors, fundamental combustion studies are in hand to determine the sources of smoke and flash and methods of eliminating them.

Nuclear magnetic resonance measurements on organic materials.

This Branch works in close association with Messrs. I.C.I., Ardeer and Messrs. I.M.I., Summerfield Research Station, in the development of cast double base propellants for use in weapons such as Seaslug, Seacat and Seadart. Basic work has been undertaken to establish the capabilities of case-bonded cast double base propellants as single, and dual, charges for Land Service use; new solvent systems have been developed for the manufacture of highly filled casting powders.



Large extrusion press for solventless cordite manufacture.



Vertical mixer for rubbery-type solid propellants, showing blades—the mixing pot has been lowered for removal of the propellant mix.

An improved process for manufacture of combustible cartridge cases for gun ammunition has been devised, and pilot production by this process is now being undertaken at R.O.F. Bishopton for the 105 and 155 mm. Land Service guns.

Non-destructive inspection of propellant charges is an important requirement and has been met by the installation of a 350 kV X-ray set and by the development of a pulse-type ultrasonic flaw detector; this equipment is also now installed in the R.O.F's, and is suitable for all solid propellant rocket charges currently in production.

The main work of the Propellants 2 Branch concerns composite propellants, which are the modern versions of gunpowder. There are two types currently under investigation. The first is "plastic" propellant, which consists of a mixture of polyisobutene with ammonium perchlorate as oxidiser, and other additives to alter the burning rate, or improve performance. Both small, and pilot scale, plants are operated and bulk propellant is supplied to the Rocket Propulsion Establishment for filling into motors. These are currently used for boost motors for several Land Service Weapons and for both boost and sustainer rockets for upper atmosphere research; the Skylark vehicle uses this type of propellant. More recently it has been successfully used in meteorological rockets. Another important application is for the rockets to propel the sledge on the high speed testing runway at Pendine. A possible Land Service free-flight rocket is also under investigation, in collaboration with the Royal Armament Research and Development Establishment and R.P.E.

A disadvantage of plastic propellant is that its low temperature limit of operation will not fully meet the requirements of the Royal Air Force, and an alternative composite propellant based on ammonium perchlorate with a carboxy terminated polybutadiene binder is now being studied. This type of propellant is used in the American Sparrow missile. Currently the work at E.R.D.E. is on a small scale, but a pilot plant, previously used for polyurethane propellant, is being modified for the new composition and will be brought into use later this year. The chemistry of the polybutadiene rubbers is also being studied with particular reference to the crosslinking mechanism and their ageing and oxidation characteristics.

Associated with this work there is a small section concerned with rheological and surface chemistry investigations of solid propellants, with the objective of improving their mechanical behaviour. This section also provides an advisory service for the use of adhesives, sealants and lutings in all types of conventional ammunition.

Another section is concerned with the study of heat transfer and thermal conductivity of sub-

stances of interest as rocket fuels or oxidisers. At present, work is concentrated on liquid hydrogen, where measurements of thermal conductivity in the critical region are being undertaken. Other recent investigations include measurements of the thermal conductivity of kerosene, Santowax, hydrogen chloride and ammonia over a wide range of temperatures and pressures (up to 3000 atmospheres). A test rig for the study of the combustion of gaseous hydrogen/gaseous oxygen in the region of 2-50 atmospheres is also available to provide basic design data to assist R.P.E. and others concerned with development of hydrogen rocket motors for space applications.

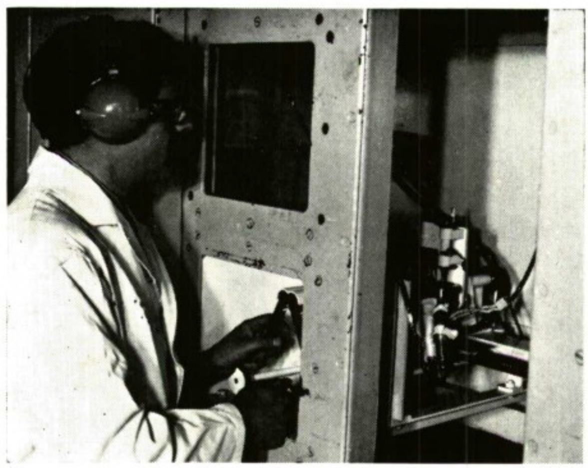
The Explosives Branch has been particularly concerned with the development of high explosive compositions with improved performance, especially for underwater applications. An increase in performance is theoretically possible, but is practicable only if means can be found for using combinations of ingredients which would be too hazardous for normal processing. A new facility where all weighing, mixing and filling can be conducted entirely by remote control is now being commissioned, adjacent to another remotely operated facility, under the Chemical Engineering Branch, where it will be possible to manufacture especially hazardous ingredients. It may also be possible to improve the performance of underwater explosives by correctly exploiting the mechanism of detonation. In conjunction with the Naval Construction Research Establishment, work is now in hand to tailor the shape of the underwater shock wave to produce the most damaging effect. A recent application of this work was to design special linear explosive charges to reproduce the shock wave generated by supersonic aircraft such as the *Lightning* and the *Concord*. This enables fairly cheap tests to be carried out with observers and on representative structures, such as glass windows in buildings. Rocket motor take-off blast pressures can also be simulated. Some fundamental work is carried out on the temperature and emissivity of the detonation front in liquid and solid explosives and on the kinetics and reaction mechanisms of the oxidation of alkyl and alkoxyl radicals by oxides of nitrogen. This latter is relevant to the stability of propellants and explosives.

The Branch also provides a service to the Establishment, and others, on sensitiveness testing of all types of explosives to impact, friction, shock and static electricity.

The development up to factory scale of safe and reliable means of producing initiators such as lead azide is also studied by the group. A number of satisfactory methods have been worked out, which are now used for production quantities by the R.O.F.'s and in Sweden and the U.S.A.

The Materials 1 Branch is concerned with the behaviour of organic non-metallic materials typified by plastics, rubbers, adhesives and fibres, in order to promote their successful use in Service equipment. All these substances are polymers and the Branch is therefore divided into sections dealing with polymer applications and development, with polymer physics, and with polymer chemistry.

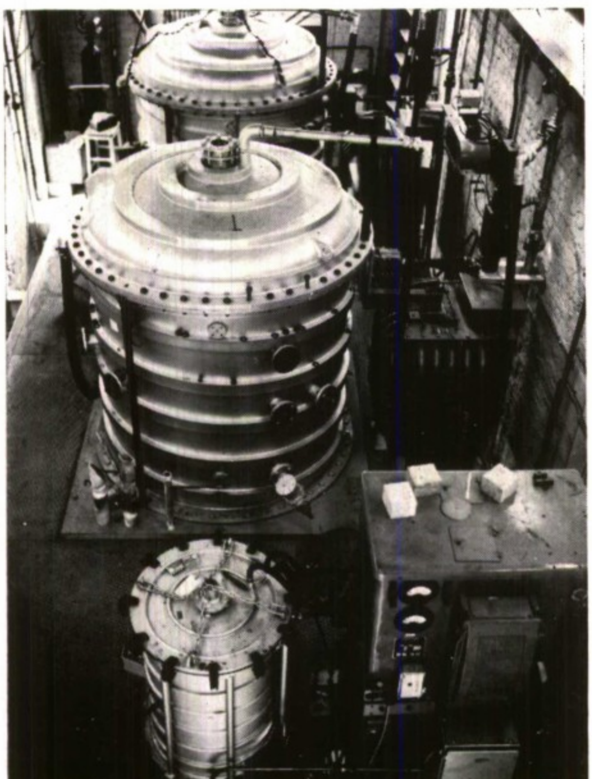
The polymer applications section is almost self-explanatory. It carries out an analogous function to the Rubber and Plastics Division of A.M.L., but in this case, Army Department establishments such as R.A.R.D.E., M.E.X.E., F.V.R.D.E. and D.S.C.(D) are advised on the choice and use of polymers, and applied research is carried out on their behalf. Examples of work include the development of Dracones, flexible fuel tanks, and more recently, conducting rubber for armoured fighting vehicle tracks. The group also liaise with the producers of polymers and examines any new development in this field.



Manipulating small 10 gram mixer for sensitive high explosives. (Part of the safety screen is opened for the purpose of photographing the equipment.)

The work of the applications section is supported by the longer term research of the other sections. The polymer physics group is primarily concerned with obtaining data on mechanical properties of polymers such as the elastic moduli and ultimate strength, for use by structural engineers. Experimental work has concentrated on the effects of temperature, rate of stress application and the influence of long term loading and fatigue on these properties. End products of this section's work include the use of non-metallic driving bands and obturating rings in shells and mortar bombs, and production of a range of instruments for measuring mechanical properties.

The chemistry section studies principally the detailed mechanism of polymer breakdown under the influence of heat, radiation or atmospheric oxidation. The work is therefore complementary to that of the corresponding section at R.A.E., which tries to synthesize more thermally stable polymers. The results of the laboratory degradation studies are related to those obtained from the exposure of specimens under tropical conditions and it is hoped to suggest ways of altering the chemical structure of the polymers to improve their stability. Characterisation of the substance is carried out using infra-red and nuclear magnetic resonance spectroscopy, molecular weight determination by osmometry, viscosity and light scattering, and glass transition temperature measurements. Extensive use has also been made of gas chromatography for analysis of decomposition products.



" Bran tubs " for synthesis of silicon nitride whiskers.

Following the closure in 1958 of the Tropical Testing Establishment in Nigeria, it was decided to set up a similar unit on a slightly smaller scale in Australia. As a result the Joint Tropical Research Unit was set up in 1962 at Innisfail, Northern Queensland, and the Materials 1 Branch runs this unit in conjunction with the Defence Standard Laboratories of the Australian Department of Supply. Currently, three members of E.R.D.E. staff are stationed at J.T.R.U. The prime function of this Unit is to expose samples of polymers, paints and related materials to tropical conditions so that the effects can be compared with similar exposures carried out in simulated facilities in the U.K. The resistance of textiles to degradation by sunlight and fungi has also been studied, as well as the effect of termites on various treated timbers.

The function of the Materials 2 Group is much more specific than that of the Materials 1 section. It has been known for many years that the theoretical strengths of materials are several orders of magnitude greater than those observed in practice, but, in certain special circumstances it is possible to manufacture very fine filaments or whisker-like crystals whose strength indeed approach the theoretical values. The production and exploitation of such substances is the main aim of this section.

The problem has several aspects. First, considerable progress has been made in the production of such materials, and pilot plant apparatus has been designed and built, which produces silicon nitride whiskers in kilogram quantities. Attempts are now being made to make silicon carbide whiskers in quantity since these have better all-round properties than the nitride. The problem is now not so much to produce whiskers but to do so economically and theoretical chemical thermodynamic studies are being carried out, using a computer, to try to select the best chemical reaction for the processes.

The physical properties of these substances make them ideal reinforcing materials but they are formed in sizes ranging from a fine dust to lengths of a few centimetres and it is necessary to sort these for selected size ranges. This problem has been successfully overcome and novel ways are also being developed to orient these whiskers with their major axes parallel. The methods are of general application and have been used equally successfully with asbestos fibres.

The third field of research is in the incorporation of the whiskers as reinforcement in suitable matrices, to produce a very much strengthened material. Thermosetting and thermoplastic polymer matrices are being used to produce strong light materials which are superior to glass-reinforced laminates. A second type of matrix is a metal, whereby the strength of the metal is retained at higher temperatures than usual. For example, aluminium reinforced with silicon nitride whiskers retains its useful strength and stiffness up to at least 300°C. At temperatures greater than 1000°C, severe problems arise because of chemical reaction between the whiskers and their metal matrices and attempts are being made to overcome this. Thus,

a polycrystalline alumina fibre has been developed which is stable for long periods in nickel alloys at high temperatures.

The Chemical Engineering Branch was originally set up, in 1948, to investigate pilot scale processing of explosives and intermediates prior to transfer to the R.O.F.'s or the Royal Naval Propellant Factory. This need has now virtually disappeared, and this Branch instead investigates important new requirements such as remote control of hazardous operations, the design and development of special equipment for other work in E.R.D.E. and the exploitation of whiskers. It is responsible for the provision of special electronic instrumentation as well as for the maintenance, servicing and repair of electronic instruments throughout the Establishment. There is also a Glass Engineering Section which supplies all types of laboratory glassware and has facilities for manufacture of special purpose glass plant, suitable for pilot plant operation. This Section provides training for scientific assistants and others in elementary glass working for laboratory purposes. Recently, the Section has developed mirrors of aluminium, or silver, on Mylar, or other plastic films, which are cheap and expendable, and which do not produce dangerous fragments, if broken—a very useful piece of equipment in an Establishment concerned with explosives. On the plant side, an intensive study of methods of measuring clearances in mixing machines is nearing completion, and the equipment is now being fitted to mixers used in the manufacture of rubbery propellants.

As part of the modernisation programme, this Branch has just taken over a new building specially designed for laboratory work in chemical engineering; this building also provides new offices for all the senior staff. Many old buildings are being completely overhauled. When this programme is completed, the facilities available for chemical engineering research and for pilot plant operations will compare favourably with any others in this country.

The Analytical and Ingredients Branch provides an analytical service for the whole establishment. It is similar in some respects to the General Chemistry Section of A.M.L. but the materials dealt with include explosives, propellants and initiators, polymers, and whisker materials such as silicon nitride and carbide. Some of the analyses are routine but many constitute minor researches and the group therefore develops new instrumental and practical techniques in anticipation of fresh problems.

Present interests include X-ray crystallography, infra-red and ultra-violet spectroscopy, mass-spectrometry, and the various forms of chromatography—gas, column and thin-layer. Thermal methods are becoming increasingly important. Special attention is paid to thermogravimetry and differential thermal analysis and a new highly sensitive isothermal heat flow calorimeter has been built. There is, in addition, a radiochemical laboratory and a small microanalysis unit which carries out molecular weight determination in addition to elemental analysis.

The second rôle of this division is to advise on all aspects of stability and surveillance of propellants, explosives and initiators, and on their compatibility with the materials with which they come into contact. In this respect, the group is the accepted United Kingdom authority, having final decision on difficulties arising in this field. It is not surprising therefore that there is considerable contact with many outside organisations such as British Aircraft Corporation, Ferranti, Hawker Siddeley, I.M.I. Summerfield, I.C.I. Ardeer as well as other Government departments including R.A.R.D.E., R.A.E., R.P.E., and D.C.I. This sort of work involves a large amount of routine testing but it is supported by more basic research on stabilisation mechanisms and kinetics of decomposition using 15N isotope labelling. The increasing use of polymer based propellants has also resulted in the initiation of work on the chemical stability of these systems.

A section of this branch studies the connection between the chemical constitution and the useful properties of the various substances which go to make a modern explosive. It also ensures that all necessary information is available about methods of manufacturing those which are actually or prospectively needed. Novel compounds required for the work of the other branches are made on a laboratory scale.

Research is in progress on the basic reaction mechanisms involved in the formation of RDX (cyclotrimethylenetrinitramine) by nitrolysis and of HMX (cyclotetramethylenetetranitramine) in the very complex conditions of the Bachmann process.

The aerodynamic heating of supersonic aircraft has given rise to the need for more thermally stable explosives and a number of these have been made. Hexanitrostilbene, in particular, is being more closely studied with regard to optimum yield and reliable conditions of preparation. Advice based on extensive studies has been given recently to R.O.F. Bridgwater on DATB (diaminotrinitrobenzene) manufacture.

The mechanism of thermal decomposition of high explosives is being studied and methods for measuring reaction rates based on decigram quantities of material have been developed.

To round off the picture of work at E.R.D.E. mention must be made of a small research group under the direction of Dr. L. J. Bellamy and Mr.

G. K. Adams. This undertakes a number of short term probing investigations, each usually by not more than one scientist, to decide whether or not a particular field merits more elaborate study.

Linked with these activities is another small section run by a special merit S.P.S.O. which is mainly concerned with the discovery of new additives to limit the spontaneous atmospheric oxidaton of polymers.

Other current research topics fall into three main groups. First, mathematical studies based on computers, of the theory of unsteady chemically reacting flow as in the growth of shock waves in explosives to steady detonation waves, thermodynamic calculations of explosive and propellant performance, and loudness calculations of real and simulated sonic booms.

Secondly, chemical studies on the production of potential laser materials such as the rare earth chelates, and the growth of metal oxide crystals by vapour phase transport.

Thirdly, what might be loosely termed "spectroscopic" studies. These comprise electron impact spectroscopy of organic molecules, field emission microscopy, and infra-red examination of hydrogen bonding and molecular interactions in solution.

In February 1967, following the dissolution of the Ministry of Aviation, E.R.D.E. became part of the Ministry of Technology. It is not anticipated that this change will significantly affect the type of work carried out, but a positive effort is being made to make a recognisable contribution in the civil field. As members of the Ministry of Technology Interlab scheme, the Establishment will be able to provide special facilities and advice on instrumentation to civilian industry. Local industry in the Waltham Abbey, Enfield, Hatfield and Harlow areas will be assisted. Nevertheless, the Establishment will continue to devote the bulk of its effort to research and development on explosives, propellants and non-metallic materials for the Defence Services, and will welcome enquiries from users or other Establishments on these matters.

Mr. Roy Mason, Minister of Defence (Equipment) visited S.E.R.L. on Friday, 10th February, 1967, for discussions and a tour of the laboratory. The Minister, right, is seen receiving an explanation of holography by Mr. Harry Foster.

The Organisation of Computer-Type Stores for the Content Associative Retrieval of Data-Processing Information

R. Benjamin, Ph.D., B.Sc., A.C.G.I., C.Eng., F.I.E.E.
Chief Scientist, Admiralty Underwater Weapons Establishment

SUMMARY

The problem examined may be considered in terms of a static "census" or ever-changing "register", producing a random sequence of reply FORMS, recorded in a computer-type store, and identified by their ADDRESS in the MAIN FILE. We are then seeking an organisation to permit the rapid retrieval or counting of all FORMS satisfying a given set of conditions, using only standard, computer-type, main and "backing-up" storage media.

In the most versatile of the solutions considered, a set of ELEMENTAL CATALOGUES of addresses is compiled, one for each logical—AND combination of those selection criteria found to be significant. These ELEMENTAL CATALOGUES are mutually exclusive but jointly fully comprehensive. CATALOGUES for particular requirements can then be COMPOUNDED by the logical—OR combination of the relevant ELEMENTAL CATALOGUES. This process may be followed by further selection, based upon a detailed examination of the actual forms, in the MAIN FILE, defined by the addresses listed in the COMPOUNDED CATALOGUE.

Certain advantages are shown to accrue if the MAIN FILE—and hence the catalogues—are divided into a number of smaller SECTIONS.

Definitions

It is believed that any special meanings of the terms used in this paper are clear in their context. Figs. 1, 2 and 3, together with the following definitions, should, however, remedy any omissions in this respect. All terms defined here will be printed in capital letters where their meaning may not be firmly established by common usage.

FORM
: a completed questionnaire, or the contents thereof as recorded in the

MAIN FILE
: which holds all the FORMS in the random order of their arrival, each FORM being identified by its

ADDRESS
: *i.e.* the location of its starting point in the MAIN FILE. At this ADDRESS, the FORM starts with an

INDEX
: giving the starting points, relative to the beginning of the FORM, of each of the standard sequences of

HEADINGS
: or groups of HEADINGS on the questionnaire to which answers of variable (or zero) length were received.

CATALOGUE
: a list of the ADDRESSES of all FORMS whose contents satisfy a given set of criteria. These CATALOGUES may be divided into

SUB-CATALOGUES giving the ADDRESSES of those FORMS within a CATALOGUE which satisfy certain additional criteria. Alternatively these

SUB-CATEGORIES
: may be distinguished by means of an identifying

MARK
: placed against the appropriate ADDRESS in the given CATALOGUE.

MASTER INDEX
: a list of the definitions, lengths and starting points of the CATALOGUES. (The starting points refer to the catalogue store, which might be separate from the main file.)

PRIMARY CATALOGUES
initial CATALOGUES compiled directly by selection from the MAIN FILE. Further CATALOGUES may then be derived (directly or indirectly) from combinations of such PRIMARY CATALOGUES by

COMPOUNDING
the appropriate PRIMARY (or COMPOUNDED)

INPUT CATALOGUES
according to simple logical rules (such as OR, AND, BUT NOT, *etc.*) to produce the desired

COMPOUNDED CATALOGUES
(as " outputs " of the compounding process).
Two or more PRIMARY or COMPOUNDED CATALOGUES are

LOGICALLY INDEPENDENT
if there is no prior knowledge that one is wholly contained within a logical combination of the others.
Each CATALOGUE has its

COMPLEMENT
i.e. the list of ADDRESSES of all FORMS *not* included in the given CATALOGUE.

AN ELEMENT
of the MAIN FILE comprises all FORMS satisfying the criteria of each of N PRIMARY CATALOGUES—or of their COMPLEMENTS. Such an ELEMENT would be an

N^{th} ORDER
one, since it satisfies N sets of criteria. An ELEMENT may have an associated

ELEMENTAL CATALOGUE
recording the associated MAIN-FILE ADDRESSES.
The significant feature of elemental catalogues (defined by different values of the same criteria) is their *mutually exclusive* nature.
It may not be practicable in a single operation to check whether a FORM in the MAIN FILE satisfies all the criteria looked for in a given search. The search may then be performed in stages, involving the production of

INTERIM CATALOGUES
recording the ADDRESSES from a given portion of the MAIN FILE satisfying those of the search criteria which have been examined up to that stage.
Two sets of logical conditions A and B may be combined on an

Inclusive OR
basis if A and/or B is wanted (*i.e.* " OR " OR "AND "). The basis of selection becomes

Exclusive OR
if A or B is wanted, but only provided the two conditions do not coincide (*i.e.* " OR " BUT NOT "AND ").
In the process of COMPOUNDING CATALOGUES, several CATALOGUES may be scanned through in a quasi-parallel manner. The MAIN-FILE ADDRESS reached in each of these CATALOGUES, at a given stage, is then the

PRESENT ADDRESS.
In certain COMPOUNDING procedures the PRESENT ADDRESSES of several CATALOGUES may be jointly treated as an

INSTANTANEOUS FILE
from which ADDRESSES are sought satisfying the criteria of the COMPOUNDED CATALOGUE. The selection procedure involved is somewhat analogous to the searching of the MAIN FILE to build up the PRIMARY CATALOGUES.
The COMPOUNDING of the two CATALOGUES A and B frequently involves searching for ADDRESSES common to both A and B. The CATALOGUE with the smaller PRESENT ADDRESS (say A) is then advanced step-by-step until it equals the (initially) larger address, or

CROSS-OVER
occurs, *i.e.* A has the larger PRESENT ADDRESS, and B is advanced step-by-step.
It may be expedient to divide both the main file and the catalogues into

SECTIONS
defined by the high-significance digits of the associated MAIN FILE ADDRESSES.
Apart from other advantages, this reduces the number of *high significance* digits that have to be recorded in each ADDRESS in a CATALOGUE.
Computer-type stores normally group the stored digits into

WORDS
of standard length.
By grouping these WORDS further into standard

PAGES
and allocating an integral number of PAGES to each FORM, the number of *low-significance* digits in each ADDRESS can be reduced and certain other advantages can be obtained.

Introduction

The " memory " units or " stores " in electronic computers or data processing systems are designed to supply, on demand, the contents of storage location N. They are not directly suitable for answering, in the appropriate systems, such questions as:—

Which documents (correspondence, scientific papers, textbooks, *etc.*) have any information on this subject ?
Have we any previous knowledge of this matter, person, *etc.* ?
Which (or how many) of our clients have shown any interest in this field ?

Which known criminals have used this *modus operandi* in the past?
What firms, machines, people might be capable of tackling this job?
Which diseases (or equipment failures) might account for the following symptoms?
What further tests ought I to apply to confirm this diagnosis?
What mode of living (operation) ought I to prescribe to live (function) as fully as possible in the presence of this disease (defect)?
What remedial action should be taken?
What goods has Mr. X ordered during the past year?
What spares were required for maintaining this equipment?
How many letters were written on this subject?
Are there any accounts that have remained " in the red " for more than a year?
How many vehicles have we available that could meet this transport requirement?
Which of these aircraft could, according to their last known position and flight plan, become a collision hazard for this 'plane?
Which is the nearest diversionary airstrip suitable for this type of 'plane?

One could carry on almost *ad infinitum* with examples of questions requiring an associative memory search, rather than address-defined memory retrieval. This paper is concerned with some methods of speeding up these associative memory searches, particularly (but not exclusively) as applied to computer-type memory units.

Files and Catalogues

The problem considered in this note is very widespread in data-processing systems. However, it can be represented, with little loss of generality, by the " filing " of answers to an extensive questionnaire (see Fig. 1).

If the serial number of the reply FORM is of special significance, or the replies given under one of the HEADINGS are numerical in nature and of special significance, there may be some advantage in filing the replies in order of increasing value of the relevant quantity. Commonly, however, the heading or combination of headings involved in searching the MAIN FILE may vary in a largely unpredictable manner from one search to the next. Hence the reply forms might as well be entered into the records in order of arrival (or in any given arbitrary sequence).

Each reference to the records must then imply some search through the file and/or reference to CATALOGUES. If future needs can be fully predicted when first assembling the file, the appropriate catalogues can be compiled there and then; otherwise the compilation, revision or modification of the catalogue itself will normally entail a search through the main-file records.

In order to facilitate the COMPOUNDING of new catalogues from several existing ones, the catalogues should select the relevant items from the main file by scanning the latter in a standard sequence (see Fig. 2). For the initial compilation and for most uses of the catalogues, it is convenient to arrange all catalogues in order of increasing address of the relevant reply forms in the main file. Indeed, for serial-address main files, this is virtually essential (see, however, later comments).

Since the catalogues will generally differ markedly in length, no standard storage space can be allocated to them. Hence a MASTER INDEX will normally be required to record the starting addresses (and lengths) of the various catalogues.

Recording the Forms

Sometimes it may only be required to determine the total *number* of FORMS satisfying the criteria defined by a given logical combination of existing catalogues. However, the initial compilation of the PRIMARY CATALOGUES, any further selection from a COMPOUNDED CATALOGUE or any examination of the FORMS obtained by any of these selection processes, requires access to the detailed replies to specific HEADINGS on the forms. Hence the position of each item on each form should be identifiable.

When most forms include replies to the majority of headings, and the replies on any one heading do not differ greatly in length from form to form, it is best to record the replies on standard PAGES with pre-allocated (not necessarily equal) spaces for all the HEADINGS. Conversely, if many headings may remain unanswered or the length of the answers to given headings is very variable from form to form, it may be preferable to provide an INDEX for each form, listing the headings covered and the starting points of these headings. The search for individual headings may then be simplified by dividing the index to the form into a " main index ", to sections of the form, together with one or more stages of " finer " indexing, for subsections of the form. Alternatively, a simple index may cover all headings of the form in a standard sequence, with a standard space in the index indicating the starting point—or absence—of each heading (see Fig. 1).

In order to simplify the main file and the catalogues, it may then still pay to round up the space allotted to each form to the next integral number of PAGES. For an exceptionally long reply, it may not always be convenient to record these pages consecutively in the main file. Nor need this be necessary, provided the appropriate cross-references can be provided.

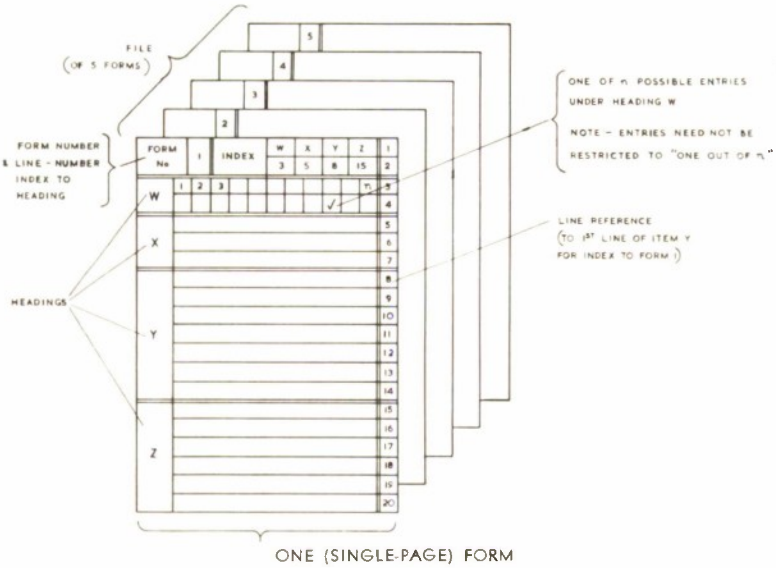


FIG. 1. File, form, heading, entry and index.

The Value of Catalogues

The purpose of the catalogues is to reduce the amount of searching of the files by listing the starting point in the main file of those replies which satisfy particular criteria. These criteria are, in general, the *existence* of an entry under a particular heading, or the return of a *specific reply* (or one of a specific sub-group of the possible replies) to a given heading on the questionnaire. Alternatively, a catalogue may list only those forms satisfying a given *combination of criteria.* Sometimes a catalogue or combination of catalogues may precisely define the relevant forms or may even contain within itself all the information sought. More generally, however, it will be used to restrict the number of forms, and the number of headings within those forms, which require further examination.

Clearly the value of a catalogue depends on the frequency with which it will be used, on the saving in search time it can give when used, and on the space it occupies.

When a catalogue is really worthwhile, the time spent on searching the files, when the catalogue is relevant and used, is insignificant compared with the time otherwise required. Hence the time *saved* is then proportional to the frequency of use, but is almost independent of the size of the catalogue. On the other hand, the space occupied by the catalogue is determined by the number of forms listed. Hence, for many purposes, the frequency of use divided by the length of the catalogue might represent a " factor of merit ". As the contents and use of a filing system evolve, information bearing on these factors of merit should be noted, so that the storage capacity available for catalogues can be put to the best use.

The above factor of merit is only applicable to catalogues covering the same initial set of data: when a catalogue pertains to a sub-selection from a broader but still restricted class, covered by an existing catalogue (or a combination of existing catalogues), its use will clearly save less search time than when, in its absence, the complete set

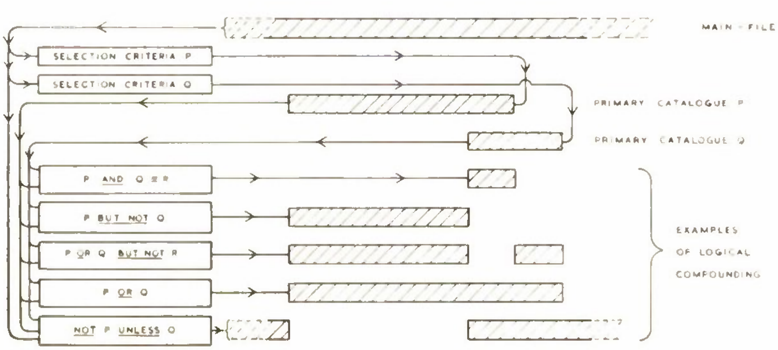


FIG. 2. Compounded catalogues.

of forms would need to be searched. On the other hand, if such a sub-category catalogue is arranged as a discrete part of the catalogue of the corresponding broader category, then it occupies no extra storage space (except in the master index to the catalogues). However, when compounding an additional catalogue X with such a partitioned catalogue P, X may have to be scanned through to compare its addresses with those of the first part of P, and the resultant, partially compounded catalogue may have to be scanned through again in the process of compounding it with the next part of P. (See Compounding two Catalogues later). This process can be speeded up somewhat, as indicated later under Multiple Compounding and Accelerated Searches, but it is still likely to entail an increased compounding time for a given complexity. (No such problem arises if the catalogues P and X are mutually exclusive and the address sequence of the resultant catalogue is immaterial, as indicated later under strategy of Catalogue Compounding).

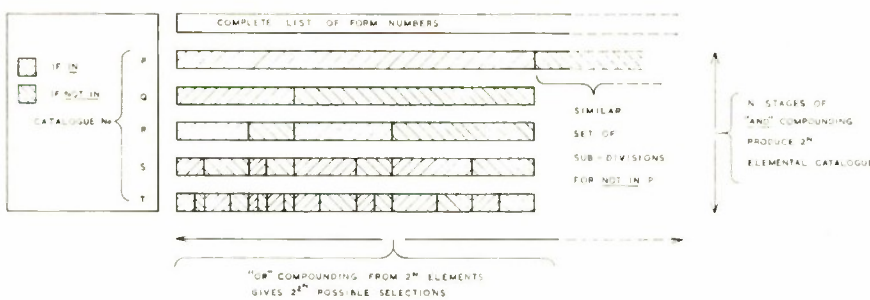


FIG. 3. Multi-stage compounding from logically-independent catalogues. To simplify diagram forms meeting common criteria are shown as occupying consecutive main file addresses.

Selection Power of Catalogue Compounding

Two or more PRIMARY CATALOGUES can be combined, according to a variety of possible logical rules (such as NOT, AND, OR, BUT NOT, *etc., etc.*) to form a wide range of COMPOUNDED CATALOGUES. (See Fig. 2). If the PRIMARY CATALOGUES are LOGICALLY INDEPENDENT (*i.e.* none is by definition or prior knowledge wholly contained in a logical combination of the others), N PRIMARY CATALOGUES can yield $2^{2^N}-2$ COMPOUNDED CATALOGUES as shown below. (The "-2" term arises from the deletion of the true but trivial cases of "all forms" and "no forms"). This obviously provides a very wide choice of possible COMPOUNDED CATALOGUES, as indicated in the table above.

Primary Catalogues (N)	1	2	3	4	5
Possible Compounded Catalogues ($2^{2^N}-2$)	2	14	254	65,534	4,294,697,294
Logically Unique Elements (2^N)	2	4	8	16	32
Minimum Size of Catalogues (2^{N-1})	1	2	4	8	16

This formula can be derived as follows (see also Fig. 3):—

Each catalogue divides the main file into two portions, " in " and " not in " that catalogue. Similarly, it splits any LOGICALLY INDEPENDENT catalogue into two such portions a third logically independent catalogue splits each of these portions into two sections. Thus each logically independent catalogue produces a further stage of binary sub-division of the smallest elements defined by the combination of the previous catalogues. Hence N logically independent catalogues can divide the overall filing system into 2^N logically unique ELEMENTS of ORDER N. These ELEMENTS are then incapable of further subdivision if they are to be defined solely in terms of the given catalogues (and their COMPLEMENTS).

Each additional primary catalogue divides the forms within each element defined by the compounding of previous catalogues into those included and those not included in the " new " cata-

logue. Thus all the successive sub-divisions are based on mutually exclusive rules, and at all stages (all values of N) each form will appear in one, and only one, of the elements so far defined, *i.e.* of order N. (However, some of the combinations of conditions, implied by these elements, may not be satisfied by any of the forms, and hence some of the potential ELEMENTAL CATALOGUES may, in fact, turn out to be of zero length).

We are now concerned with the total number of distinct patterns that can be generated from the linear mosaic of 2^N logically unique elements, cf Fig. 3, by selecting combinations of these elements. Obviously all possible composite patterns are covered (non-redundantly) if, in the design of the pattern, each element is separately considered and either included or rejected. Each of these 2^N binary choices doubles the number of possible patterns available in its absence, thus providing a total choice of 2^{2^N} possible patterns (including the trivial, limiting cases of acceptance or rejection of the complete " mosaic "); Q.E.D.

It must be stressed that the concept of logical independence implies that there is no *a priori* knowledge that precludes any primary catalogue from including *some—but not all*—the members in each of the 2^N elemental sub-divisions definable by the other N-1 catalogues. Where this condition is not satisfied *a posteriori*, some of the 2^N elements will in fact vanish, and hence some of the composite patterns will in fact be identical. Indeed, if any primary catalogues should include fewer than 2^{N-1} entries, we can conclude *a priori* that this degenerate condition must exist—but, unfortunately, we would have only limited information on where it exists. In any case, the minimum number of forms per catalogue required to preclude such *a priori* knowledge is very small—as indicated in the table above. (It is assumed that each catalogue covers less than half the complete file, and so the upper limit, total number of forms minus 2^{N-1}—where the *complement* cannot include entries in all the combinations of the other catalogues—does not arise.)

The Compilation of Primary Catalogues or of Sub-Selections from Single Catalogues

By definition, PRIMARY CATALOGUES are constructed by direct selection from the main file. Hence their compilation entails searching the forms in the main file, one by one, to see whether they satisfy a given set of combinations of criteria:

(i) Where the replies to the questionnaire are independent " nominal " classifications, these criteria are necessarily restricted to the presence or absence of particular replies—or " binary logical " combinations thereof.

(ii) Where the replies fall into an " ordinal " classification, the criteria can take the form of " above " . . ., " below " . . ., " between " . . . —or of more complex " multivalued logical " rules.

(iii) Where the replies are " quantitative ", the criteria can of course take any " algebraic " form.

Hence the compilation of primary catalogues entails an exceedingly simple sequence-control programme, for scanning through its single source of input data. This function becomes considerably more complex when compounding several logically independent primary catalogues. On the other hand, the search criteria combining conditions such as (i) (ii) and (iii) above, for the compilation of primary catalogues, may be of considerable complexity—as compared with those of catalogue compounding which are intrinsically restricted to binary logical combinations of the (primary or compounded) " input " catalogues.

It should be noted that, following the compounding of appropriate existing catalogues, a given retrieval task may entail searching the forms defined by the catalogue compounding process for " replies " satisfying certain additional criteria. This process is closely analogous to the compilation of a primary catalogue and, similarly, may entail the use of fairly complex search procedure.

It is thus quite likely that the logical circuits available do not permit a main-file form to be tested for all the relevant criteria in a single set of parallel operations. Hence the search criteria may have to be expressed in the form of several suitable partial sets of criteria, and the compilation of a primary (or sub-selection) catalogue may have to be performed in several consecutive stages. The first (partial) set of criteria applied should then normally be the most highly selective one, in order to limit the number of forms that have to be passed on to the further stages of selection—still probably applied in order of decreasing " selectivity ".

In some cases a relatively significant amount of time may be taken in changing the criteria test unit from one set of partial search criteria to the next. If, then, the forms to be searched are already in the main file or come in from the outside in batches, it may pay to record the addresses of consecutive forms meeting the given partial criteria in an " interim catalogue ", until the storage space available for such an interim catalogue has been filled—or the batch has been searched. The search logic can then be altered to the next set of partial criteria and the same set of forms can be scanned again, but this time profiting from any pre-selection defined by the interim catalogue. In order to fill the same interim catalogue space, successive stages of logical selection would normally correspond to

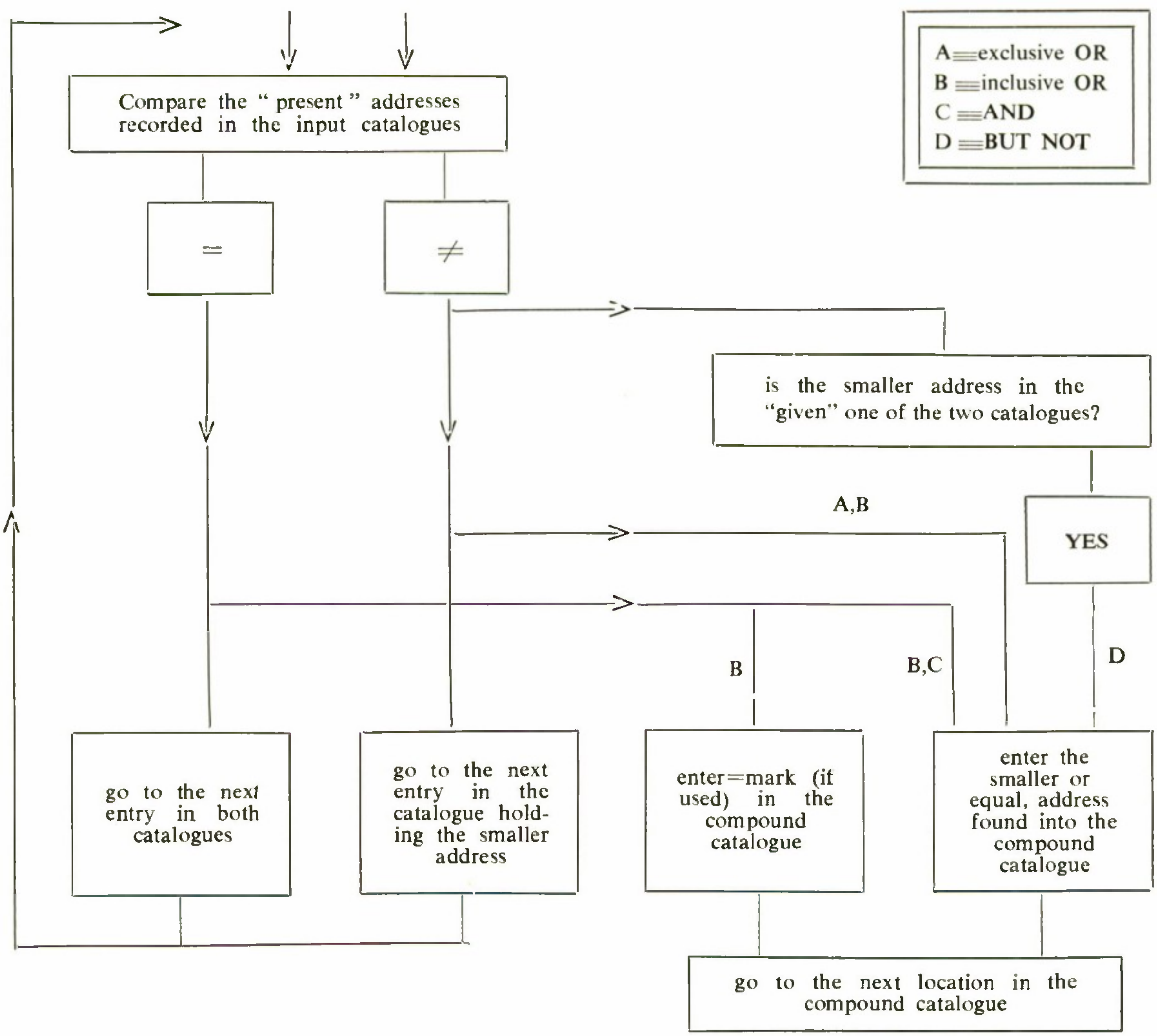
progressively larger numbers of "unfiltered" main-file forms.

Compounding Two Catalogues

It has been shown that any possible catalogue can be built up by the OR combination of the appropriate "mosaic elements", where these elements are defined by the AND combinations of the primary catalogues (and their complements). But both AND and OR functions can self-evidently be built up step by step, each step compounding one more catalogue with the resultant of previous compoundings. It may of course be both permissible and expedient to compound two existing catalogues without first sub-dividing them into their smallest resolvable ELEMENTS (in the case of PRIMARY catalogues 2^{N-1} each). In any case, a facility for compounding two catalogues on an AND or OR basis (or equivalent logical facilities) would clearly be sufficient for building up any possible compound catalogue. However, a wider range of logical functions would normally permit a given catalogue to be built up more economically in both time and programming.

A programme for compounding two catalogues according to any one of four logical rules is shown below, in simplified schematic form.

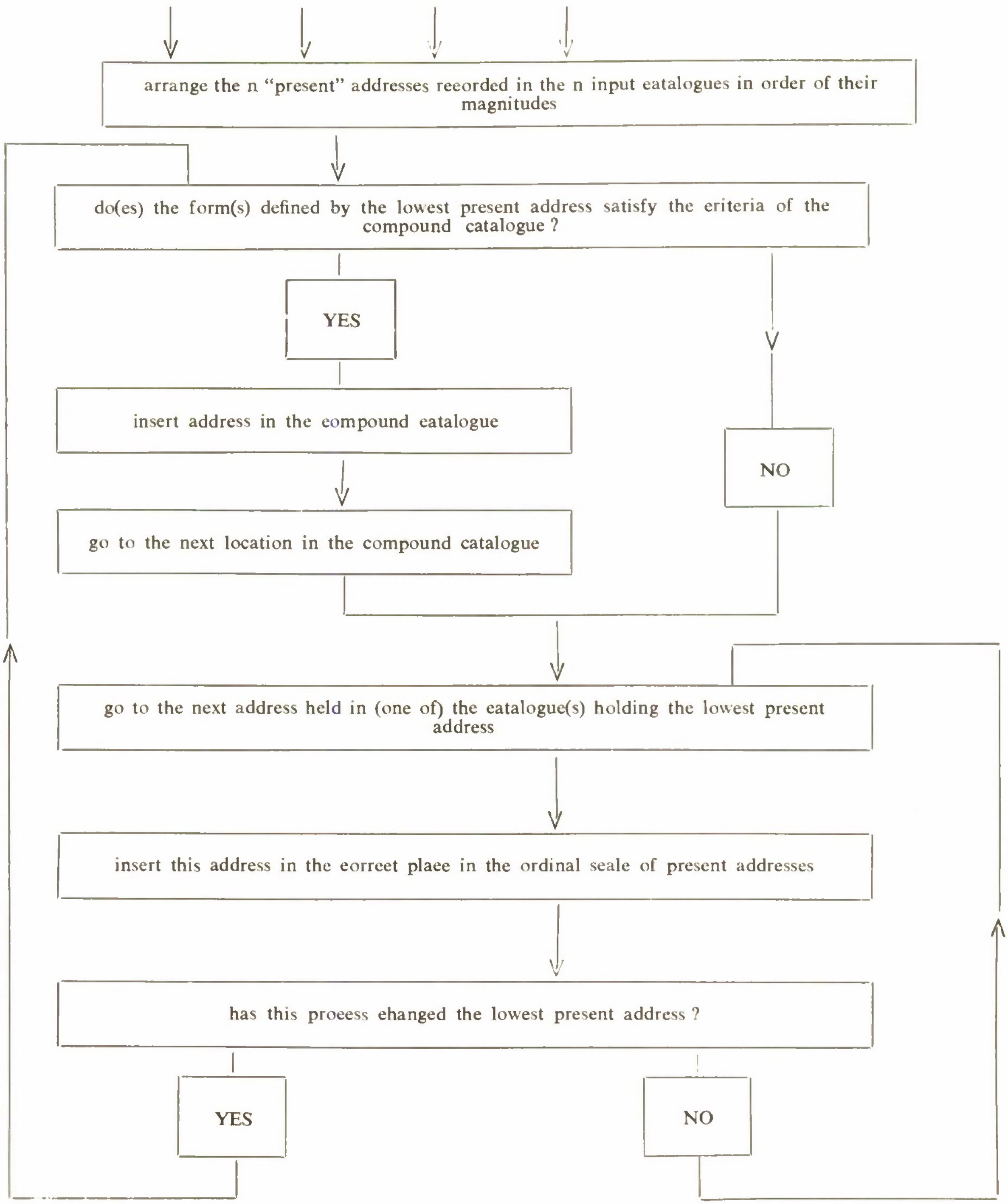
The bifurcated loop on the left shows the com-



mon iterative control cycle. The top right-hand corner lists the four logical functions provided (inclusive OR means OR or AND, exclusive OR means OR but not AND). These compounding functions are then performed on the lower right of the diagram, by activating only the lines marked with the code letter of the desired function.

Simultaneous Multiple Compounding

The more efficient the compounding facilities, the fewer non-primary catalogues need be permanently stored. Clearly it would be useful to be able to compound from n ($n>2$) primary catalogues in a single operation. A programme for doing this is shown in schematic form below:—



This programme starts by taking the form of lowest address from each of the n catalogues, arranging these n forms in order of increasing address, and treating them as a single instantaneous file from which the appropriate selection is to be made. Each of the n addresses in this " instantaneous file " must carry the reference number (between 1 and n) of the originating primary catalogue. This reference number may be used in the logical criteria defining the compound category to be formed. In any case, it will be required to replenish the " instantaneous file " as successive " lowest remaining addresses " get examined—and hence discarded from further consideration.

When the lowest address has been dealt with (and transcribed into the compound catalogue or not, as appropriate) the next address from the relevant primary catalogue is selected and inserted in the proper place in the INSTANTANEOUS FILE. If the lowest address in the instantaneous file was common to several of the n primary catalogues, several replenishment and re-ordering operations will be required before the instantaneous file has a new " lowest present address " available for examination. Hence the lower right-hand loop of the diagram.

To give the full potential benefit of this programme, the second block of the diagram may have to provide a fairly extensive repertoire of logical functions.

Accelerated Address Searches

If powerful compounding facilities are to take the place of a large array of permanent compound catalogues, it is also worthwhile to consider various short cuts. For instance, when combining two catalogues according to an AND criterion, the " present " address in catalogue A may be d less than the present address in catalogue B. If the average spacing of the remaining addresses in catalogue A is known to be s, it may pay to advance the present address in A by d/s entries (rounded off) rather than to advance it one step at a time. If the new address so found still differs significantly from that in B, the process can be repeated with respect to the new smaller value of d. This time, however, d may be either positive or negative, calling for an increase or decrease, respectively, in the A address. Eventually the A address will, of course, have to be altered one step at a time until it either equals or " crosses " the value of the present B address.

A simplified version of this principle is as follows:—

If catalogue A has *a* entries and catalogue B has *b* entries, where a $>>$ b, then each advance of catalogue B by one step might be matched by a jump advance of catalogue A by *a*/*b* steps, followed by single positive or negative steps until the CROSS-OVER is reached. (The magnitudes of *a* and *b* would, of course, be known from the master index.)

More generally, after each step we know the direction (positive or negative) of the next step, and we have some basis on which to assess either its most probable or its mean probable magnitude. Even very crude approximate algorithms can give very marked savings. (For instance, if the maximum possible step is initially P, we could ignore all probabilities and make progressive steps of P/2, P/4, P/8 . . . in the appropriate directions, thus giving a maximum of $\log_2$ P instead of a maximum of P search steps).

Such an accelerated *AND* search can be used to synthesise other logical functions. For example its resultant should be deleted from A (or B) to give A *BUT NOT* B (or B *BUT NOT* A), it should also be deleted from either A or B before combining these, to give A *OR* B (*inclusive*), and it should be deleted from both A and B before combining these to give A *OR* B (*exclusive*). This type of operation is greatly facilitated if the relevant addresses in the individual catalogues (such as A and B) can have marks inserted against them to indicate that they meet given additional criteria (in this example A AND B).

A programme for compounding N catalogues might also include provisions for profiting from special logical conditions. For example, if the criterion were A *OR* B *OR* C *OR* D . . . *OR* N-1, *BUT NOT* N, all catalogues whose present address is less than that in N could transcribe their present non-identical addresses to the output catalogue and then advance to their next address, until the present address of N is smaller than all the others, when N would advance to its next address. Sequential ordering of the present addresses of catalogues A to N-1 might be convenient but would not be essential.

The Strategy of Catalogue Compounding

When the desired selection is compounded from more input catalogues than can be handled simultaneously, the compounding has to proceed in stages. The catalogues that have to be scanned through in the first stage of compounding have then to be scanned through again—though in their first compounded and therefore probably shortened form—in the next stage of compounding. Hence it will normally pay to organise the sequence so as to use in each stage of compounding the shortest relevant catologues available at that stage. When two catalogues are in fact mutually exclusive parts of a more general catalogue, their initial compounding on an OR basis (prior to other compounding operations) results in no reduction in the size of the

compound catalogue and may entail a significant waste of time as indicated previously under the value of catalogues.

On the other hand, when all the primary catalogues take the form of 2^N mutually exclusive ELEMENTAL CATALOGUES (see Selection Power above), the total number of primary catalogue entries will always equal the total number of forms in the main file, without replication. All $2^N - 2$ compound catalogues would be available by OR compounding these elemental catalogues, and the compounding logic would be simplified by the known mutually exclusive nature of all catalogues used at all stages in such a compounding operation.

If the sequence of the addresses in the final compound catalogue is immaterial, the compounding of elemental catalogues need entail no more than the use of the relevant separate elemental catalogues in any arbitrary sequence. This favourable situation arises:—

(i) if the purpose of a search is only to find the *number* of forms satisfying the given criteria; or

(ii) if the number of addresses given by the search will be so small that it will be an insignificant task to rearrange them in order of increasing main file addresses; or

(iii) if the main file is capable of fast jumping from any address to any higher address (and of rapid re-setting to the start—or of fast reverse scanning); or

(iv) if the main file is a random access store.

Requirements of Catalogue Storage

The strategy of catalogue compounding may be restricted by the nature of the catalogue stores. These, of course, need not necessarily be physically part of, or take the same form as the main file. The simultaneous compounding of n catalogues requires, as a minimum, that these n stores and their compounded resultant be recorded on the equivalent of (n + 1) independent, sequential-address, start-stop operated stores. The catalogues currently required for compounding might of course be initially transcribed onto suitable stores from some other storage medium of lower versatility but, say, lower cost or greater capacity.

For accelerated compounding procedures, these stores should be capable of multiple address jumps and of reversible operation. (Separate recording of the catalogues in order of both increasing and decreasing main-file addresses could be used in lieu of reversible address scanning). For multi-stage compounding, facilities for rapid re-setting to the initial or final address are most desirable. This would permit the resultant of one stage of compounding to be included without delay in the next stage of compounding, if necessary by proceeding from the largest address " backwards " towards the smallest.

Catalogue and Main File Configurations for Static Populations

When the main file is static, *e.g.* in a census, the time taken in compiling primary catalogues may be relatively insignificant. On the other hand the population covered by the main file may be very large, and hence it may be important that all catalogues cover the population in the correct main-file sequence, and that any desired catalogue can be derived by compounding the minimum number of input catalogues. A large library of catalogues can then be carried in inexpensive sequential access storage, and those catalogues involved in a particular search can be transcribed (in sections, if desired) to more versatile forms of storage, prior to compounding. These conditions involve no inconsistencies and can result in an effective and (relatively) economic filing and associative retrieval system for static populations of data.

Catalogue and Main File Configurations for Register-Type Files

Rather different conditions apply if the main file records the instantaneous state of a constantly changing population (*e.g.* a hotel register). In this case, forms have to be continually inserted in any vacant spaces in the main file, and their addresses have to be added in the correct places in all relevant (primary and compounded) catalogues, as new clients check in. As the clients order and then use assorted services, their form needs continual amendment, and its address continually needs inserting in new catalogues or deleting from others. Finally as the clients pay their bill and check out, their form may be deleted from the main file and from all relevant catalogues—or may be suitably re-classified. Each of these changes entails a re-shuffling of the address sequences in each of the catalogues affected and may also have repercussions on the master index to the catalogues.

In these circumstances there are major advantages in storing only " elemental catalogues ":—

(i) The " old " contents of each form will then define uniquely the one and only elemental catalogue from which its address may need deleting.

(ii) If the catalogue does need changing, the " new " contents of the form uniquely specify the one and only elemental catalogue to which its address must be added.

(iii) If the main file can be operated as a random-access store, the addresses in the elemental catalogues need not be arranged (and continually re-arranged) in order of increasing magnitude. However, this entails a longer search for the given address within its catalogue.

(iv) Since no change can require the amendment of a form or addition of a new form in more than one elemental catalogue, and these catalogues are, by definition, as short as the logical tests made permit, the work entailed in any re-shuffling of addresses in order of ascending magnitude is minimised. Similarly the search for an address to be deleted from a random-sequence elemental store is minimised.

In addition, elemental cataloguing has of course always the advantages pointed out or implied in the section on Selection Power and Compounding Strategy, *i.e.*:—

(v) because each FORM appears in only one elemental catalogue, the total catalogue space required is likely to be minimised;

(vi) compounding can never entail more than additively combining, in an acceptable sequence, the (necessarily unique) addresses contained in the relevant elemental catalogues.

In "Hotel-register" type systems, it is clearly convenient to allot a standard amount of storage space to each FORM so as to be able to insert new forms in the spaces left by cancelled ones. With sequential-access stores this is virtually essential. Exceptionally, however, a double-length space could be created by transcribing a form adjacent to a single vacant space into another vacant space elsewhere in the main file, and amending the catalogues affected accordingly. Rapid or random-access stores would provide more freedom for exceptionally long forms to fill several standard spaces, at arbitrary addresses (at any rate within one SECTION, see below). The initial index to the form would then have to give the addresses of all parts thereof, or else each "instalment" of the form might give the address of the next instalment.

If each form occupies an integral number of standard PAGES of storage, then the longer the PAGES, the more main file storage may be wasted, but also the smaller is the range of PAGE numbers to be covered by the addresses in the catalogues.

Sectional Main Files and Catalogues

A number of important advantages can be gained by dividing the main file and all the catalogues into 2^h consecutive sections, as defined by the h highest-significance binary digits of the relevant addresses:—

(i) It reduces the number of address digits which need be recorded in the catalogues. If the catalogue storage medium is organised in "words" of a given number of digits, this may permit, say, one more address to be accommodated within each "word" of the catalogue store.

(ii) When compounding catalogues which are not elemental (or otherwise mutually exclusive), it reduces both the potential discrepancy between the addresses requiring to be compared and the number of addresses with which any one address may need comparing. (Clearly no problem would arise in reading consecutive sections in an address-sequential manner, section-to-section whether or not they are *individually* compounded in this manner within each section.) Hence it speeds up the compounding operation.

(iii) It speeds up modification of catalogues due to changes in the main file, by reducing the search for the relevant address in the catalogues.

(iv) It adds no complication to the initial compilation of primary catalogues; indeed it may speed this up markedly when the compilation entails multi-stage selection (see section on Compilation of Primary Catalogues), if a basically serial-access main file can be transcribed, one section at a time, onto a rapid-access storage medium.

(v) When compounding elemental catalogues (divided by their high-significance address digits into further individually smaller sectional elements) the OR combinations of the small sectional elements can be fairly readily organised in order of ascending address, if required. The ordering of the resultant sectional compound catalogues is of course already implied in the sections.

(vi) If one section at a time of the main file can be made available in random access storage, the elemental catalogues of a given section may be compounded by "stringing together" the appropriate forms in any arbitrary sequence.

Conclusion

(i) The stores of present-day electronic data processing systems do not offer any analogue to the edge-slotted card filing system, in which a single operation (*i.e.* inserting a "knitting needle" and shaking) can *in parallel* sift out from any

random assembly of cards those satisfying a given criterion (*i.e.* possessing a given edge slot, rather than an isolated hole).

(ii) Suitable design and organisation of electronic stores, with appropriate catalogues and logical circuits, can however provide very versatile and powerful facilities for associative information retrieval.

(iii) These facilities do not depend on the development of new or hypothetical techniques or components.

(iv) For this purpose the " main file " may be divided into coarse-address " sections " which can if necessary be transcribed, one at a time, into a random-access store.

(v) Sectional " elemental catalogues " can then sub-divide the addresses of each section into mutually exclusive logical elements of minimum size.

(vi) These or more complex catalogues may be compounded according to the requirements of any particular search.

(vii) The " forms " listed in the resultant compound catalogue can then be submitted to further logical tests, using only facilities required in any case (for the initial compilation of the catalogues).

MR. L. E. S. MATHIAS

Mr. L. E. S. Mathias has left S.E.R.L. to transfer to Australian Government Service (on approved employment terms). He will take up the post of Head of the Basic Research Group (Physics) at the Defence Standards Laboratories, Maribyrnong, Victoria. Mr. Mathias, who was 18 years at S.E.R.L., worked on high power microwave tubes and gas discharge lasers. He was the first to obtain laser action in a molecular gas (nitrogen) and has since made many contributions to lasers and built up an international reputation in this field.

We offer Mr. Mathias our best wishes for the future.

OIL POLLUTION FROM THE *TORREY CANYON*

W. E. L. Taylor, B.Sc., A.Inst.C., R.N.S.S.
Admiralty Oil Laboratory

Much has been written and said on the problem of oil pollution produced by the wreck of the *Torrey Canyon*, on the 18th March on the Seven Stones Reef off Lands End, and a great deal has been without first hand knowledge of the problem and conditions. The number of ideas and suggestions put forward to solve the problem have been so numerous, it will take months to investigate them.

As invariably happens when a major catastrophe occurs it takes quite a while for a co-ordinated plan to emerge, and over a coastline as long as Cornwall it is inevitable that every local council tackled the problem to the best of its knowledge and, with the influx of many " experts " with commercial interests the situation at times became very confused. On the formation of the Operations Headquarters at Plymouth, the Naval Contracts Department were inundated with sales representatives but they were soon advised that the types of materials to be used to combat the pollution should be laboratory approved and for this purpose the Warren Springs Laboratory (Ministry of Technology) and the Admiralty Oil Laboratory were both geared up to test these products. Both these laboratories have had previous experience of the problem of oil pollution. Between 1960-1963 the Warren Springs Laboratory published a number of reports on the subject, and the principles contained in these reports have been used in the present crisis. The Admiralty Oil Laboratory has been involved in oil pollution over a period of twenty-five years but owing to a very low priority, hardly any laboratory work had been carried out until about two years ago when it was required to investigate suitable materials for cleaning ships' bilges. As recently as March of this year, the Admiralty Oil Laboratory assessed a number of commercial products for treating oil spillages in Devonport Dockyard. It was fortunate that a number of detergents suitable for oil pollution treatment were available in Naval Stores, in sufficient quantity to meet immediate Naval requirements on the day the *Torrey Canyon* foundered. In a matter of days, Industry had stepped up its production to provide the Naval Stores Department with 70,000 gallons a day to meet all requirements of the Navy, Ministry of Local Government and Housing and the Local Authorities of Cornwall.

In the *Torrey Canyon* disaster, the co-operation provided by the Admiralty Oil Laboratory was two-fold, in that it provided technical assistance on the beaches and carried out a considerable amount of Laboratory work to assess the numerous commercial products claiming to disperse or sink the oil. From this work, the Laboratory was able to keep the Contracts Department informed of any changes in the products to purchase.

This article can be considered to be introductory to a further article which will deal with the laboratory tests carried out in support of the field operations. The Author, in the course of providing technical assistance, visited many areas of Cornwall, and this article describes the various types of pollution encountered and some of the methods used to eliminate them.

Because, at the time, no satisfactory material which would successfully sink the oil was known the general principle of treating the pollution with detergents was used, in order to produce an " oil in water " emulsion which could readily be dispersed in the sea. As much as possible of the oil released by the *Torrey Canyon* was sprayed with detergents at sea from ships and it was hoped that wave action and the movement of the ships would provide sufficient agitation to emulsify the oil with water and disperse it. It can be expected that when such large quantities of oil are encountered, as in this case, some of the oil will reach the coast. The Cornish Coast was saved from a worse disaster by a change of wind on the 26th March, causing a split in a very large slick of oil, south-east of Land's End, and a very large area of oil drifted away from the coast down the English Channel.

Part of this oil contaminated the French Coast, and even now, after two months, there are patches of oil—one is reported to be a mile in length by $\frac{5}{8}$ miles across—still floating around the Bay of Biscay. Another change of wind could result in this floating oil being deposited on the South Coast, anywhere between Dover and Land's End. The movement of the oil slick after the disaster could, under different conditions, have resulted in more severe pollution of the English Coast.

For the first few days after the 18th March the prevailing winds off Lands End were in a North-westerly direction, but a change in the direction of the wind to the West on the 24th March, allowed some of the oil to seep up the North coast of Cornwall as far as Newquay but the majority remained at sea south of Lands End. This change of wind to the South-west, however, produced a bulbous head at the southern end of the slick, which finally broke off and drifted down the English Channel. This change of wind also caused some of the oil to contaminate the western side of the Lizard Head from Marazion to Mullion Cove.

At the time of the foundering, the *Torrey Canyon* was carrying approximately 120,000 tons of Kuwait crude oil and *ad-hoc* laboratory experiments at A.O.L. and elsewhere have shown that in twenty-four hours weathering approximately 25 per cent of volatile oil is lost by evaporation and after three days 30 per cent is lost. The loss of these components results in the residues being more viscous and more easily emulsified with sea water than the original crude oil. When the water content of this " water in oil " emulsion increased from approximately 40 per cent to a maximum of 75 per cent, the colour changed from black to chocolate-brown.

As the water content in these " water in oil " emulsions increases the more difficult it is to convert the oil into an " oil in water " emulsion with the detergents being used in the cleaning-up operations. It is possible that if only traces of detergents from the spraying operations are present in the original crude oil, the rate of formation of " water in oil " emulsion may increase, or it may be that the chocolate-brown emulsion is a mixture of both types of emulsion. Up to the present, very little laboratory work has been carried out to determine the exact nature of these emulsions. Both types of pollution, *i.e.*, neat oil and emulsified oil, reached the beaches and rock areas. Many sandy beaches, which had absorbed oil in depth, were later covered with new sand. The contaminated sand proved to be the most difficult of all forms of pollution to clean-up.

FIG. 1. Firemen washing beach with high pressure water jets.

FIG. 2. Oil and sand mixture with a consistency of clay.

FIG. 3. Pollution down to a depth of 6 to 9 in.

FIG. 4. Trenches bulldozed towards the sea.

Two further types of pollution were also observed during a reconnaisance of the coast, one being in the form of black discs deposited on the beaches at high tide marks, and the other had the appearance of milk chocolate drops which were also deposited at the tide levels. The black discs varied in size from a sixpence to a saucer, and consisted of a highly viscous emulsion containing approximately 30 per cent water, whilst the chocolate drops contained over 60 per cent water. The formation of the latter contamination can be explained in the following manner.

The oil and emulsion, which deposited on the rock areas of the coast in a layer approximately ½ in. thick and in the rock pools up to 12 in. in depth, took up further water on being pounded by the sea at high tides and as the water content increased so the adhesion of the emulsion to the rocks decreased, and the emulsion fell away into the sea. In the eddies around the base of the rocks, the emulsion broke into smaller spherical particles which on the falling tides were swept out to sea to be deposited on the beaches on the following high tides. Because of the reduction of the interfacial tension of the emulsion and the water, these spherical particles do not coagulate to produce a solid oil slick. The breaking up of emulsions into smaller patches can also take place at sea in stormy weather and according to French reports, it would appear that the pollution in the Bay of Biscay is of this type.

FIG. 5. Close-up of a trench showing depth.

FIG. 7. Bulldozed trenches at Sennen Cove.

FIG. 6. Hosing down rocky coastline.

As previously stated the pollution at sea was treated by spraying detergent from ships, but when the oil reached the shore, the cleaning of the main holiday beaches was given the first priority: the Local Authorities' staffs being augmented with Army and Fire Brigade personnel.

The initial method of cleaning the rocks and sand was to spray detergent and then allow the tide to wash the area. This was only partially successful because the deposition of the oil coincided with the highest tides of the century and oil was deposited above the normal tide levels. The method used to tackle the areas unwashed by the tide, was to spray the detergents and then wash the sand with high pressure water jets using fire hoses. (Fig. 1).

The American Army and some Local Authorities adopted the principle of injecting the detergent into the washing water. This method is wasteful because the preceding introduction of water to the detergent only emulsifies the solvents which carry the active agent into the oil to produce an "oil in water" emulsion for dispersion. The force of the water jet removes the oil from the rocks without completely emulsifying it, and it could be re-deposited elsewhere.

It was evident that these methods were inadequate for oil contaminated sand and mechanical methods would have to be employed. The largest mechanical operation was carried out by the Royal Engineers on Porthmeor Beach, St. Ives, which was one of the most heavily contaminated beaches in Cornwall. In this operation A.O.L. and the Warren Springs Laboratory worked in close liaison with the O.I.C. Trials, and set up a mobile laboratory at Porthmeor to analyse, as the work progressed, samples of sand for oil content. In addition, this laboratory was used to test sand samples from 31 beaches and coves between Newquay and Port Leven.

The oil reached the Porthmeor Beach on the 27th and 28th March in the form of a dark chocolate-brown coloured oil slick, which covered the whole beach, including the rock outcrop, to a depth of several inches. As some of the oil came in with the tide, it mixed with the sand to form large patches of pollution, which had the appearance of flat shallow rock and a consistency of black clay (Fig. 2). Immediate action was taken by the Local Authorities with the help of the Army and Fire Services personnel. The beach was sprayed with detergent and the emulsification was assisted by using high pressure jets of water. At the same time and for many days afterwards, a flotilla of small boats was spraying detergents on the oil slicks in the bay. This action was only partially successful mainly because of the very heavy contamination, which, because it had been in contact with the beach for several days, a considerable amount of oil had penetrated into the sand and the beach above the water table was polluted to a depth of 6 to 9 in. (Fig. 3). The natural self cleaning action of the sea (*i.e.* saturation on the rising tide and leeching) was impaired by the impermeable layer of oil and sand and it is doubtful whether this layer would have broken down for months or even years.

Before any large scale movement of beach sand can take place it is essential that the local conditions of tides, wind and sand movement are investigated. On the North Coast of Cornwall, onshore winds tend to move the sand away from the beach into the bay whilst off-shore winds tend to bring back sand from the bay on to the beach. At St. Ives, the sand movement is mainly confined to the bay and does not affect other areas. Generally speaking, the Porthmeor Beach is stripped to bedrock in the winter and during the Spring and early Summer as much as four feet of sand is returned to the beach.

The initial plan for the moving of the contaminated sand from Porthmeor Beach was to strip 9 to 12 in. of the beach from the High Water Level Springs to the centre at the High Water Level Neaps, followed by spraying the heaps of sands with detergent and finally moving the sand to the Low Water Level and using the tide to break up the clotted sand into individual particles to wash it free of oil and detergent. At this time, the winds were onshore and it was hoped that the sand would be deposited below the Low Water Level. The initial plan was modified, and the contaminated sand was pushed straight down to the Low Water Level when it was found that the tide and currents tended to work the sand and move it to the centre of the beach, thus saving a great deal of earthmoving effort. It was fortunate that the operations coincided with neap tides and the wind was on-shore, thus ensuring a maximum movement of sand. A total of 30,000 tons of sand were moved by R.E. earthmoving equipment during these operations.

Before and during the operations, samples of sand were taken from various points on the beach and the oil contents determined in the field laboratory. The analysis of the initial samples indicated that the sand contained 22-33 fluid ozs./cu. ft., suggesting that the original deposition of oil on the beach was approximately 250 tons. After the completion of the Army Trials, the analysis indicated that approximately 5 tons of oil were still contaminating the beach and most of this was confined to one side of the bay. Work is still proceeding in this area, and the Local Authority are bulldozing the sand towards the sea (Figs. 4 and 5), spraying the sand lightly with detergent and allowing the tide to wash the sand. The work appears to be giving good results as is indicated by the leeching of oil into the channels, which are now below the water table of the sea. The removal of the last traces of oil will be a long tedious job

and it is hoped that sand analyses will be carried out to monitor the progress.

A considerable area of rock outcrop cannot be worked with mechanical equipment and it is proposed that the sand areas between the rocks are dug over with spades, sprayed with detergent before washing either by the sea or with water hoses; most of the rocks have been cleaned by spraying with detergent and washing down with water (Fig. 6). By the middle of May, two thirds of the Porthmeor Beach could be considered clean, but the remainder will take some time to clear before visitors are allowed to use the beach.

Sennen Cove was the most heavily contaminated beach seen; on the first visit at the beginning of April, there was a very large area, nearly eighteen inches deep, consisting of a semi-liquid mixture of oil, sand and water. Although the work has gone on continuously for a month, very little progress has been made to clear the oil. At the present time, the method of treatment is bulldozing with heavy equipment, in a criss-cross pattern (Fig. 7), spraying with detergent (Fig. 8) and allowing the sea to wash the sand. Figures 7 and 8 show very clearly the texture of the sand and how the oil is leeching out by this method of treatment.

Some re-contamination of all the beaches with oil and/or emulsion from material trapped in the rock area is likely to occur periodically over the next few months but if the Local Authorities carry on with the same enthusiasm in cleaning it up as they have shown in the past, then the visitors will have little to fear from contaminated beaches.

As frequently happens, the solving of one problem creates others. Thus, in the case of removing oil from beaches by using detergents the friction between the sand grains is reduced and in consequence, its load carrying capacity is also reduced (*i.e.*, the sand becomes " quick ").

If the sand becomes contaminated with emulsified solvent from the detergent much effort must be expended in turning the sand over with bulldozers, chain-harrows or similar equipment and then leaching out the solvents with the tide before the sand forms a firm surface again. In this case drainage channels should be dug across the beach, in order to prevent the loss of sand. This method of channelling was successfully used at Fistral Bay (Newquay) where the contamination of the beach was fairly heavy and the sand was of a coarser nature than at Porthmeor. The use of detergents in these operations has had a disastrous effect on marine life, and this is clearly shown in the reconnaisance of Trevaunce Cove, St. Agnes Head, which is one of the very few places on the contaminated coast where detergents were not used. The long term effect of detergents on marine life is being studied by the Admiralty Materials Laboratory. It is considered that in the absence of other suitable materials, the use of aromatic detergents in this case was fully justified but for future occasions investigations should be undertaken to see if materials and methods which will have a less harmful effect on marine life can be developed.

The Army, Auxiliary Fire Services and the Local Authorities have put in a prodigious amount of work and effort to clear the coast of Cornwall, and they should be congratulated on the results achieved. On a reconnaisance at the beginning of May, it was found that with the exception of Sennen Cove and Porthmeor Beach, the rest of the major holiday beaches were fairly clear of oil and should cause very little inconvenience to visitors.

FIG. 8. Spraying detergent.

BIRTHDAY HONOURS 1967

D. Stewart Watson, O.B.E., B.Sc., F.I.E.E., R.N.S.S.

Mr. D. Stewart Watson, O.B.E., B.Sc., F.I.E.E., of the Royal Naval Scientific Service, is to be congratulated upon the award of the C.B. in the Birthday Honours List. Mr. Watson has been the Director of the Admiralty Surface Weapons Establishment since 1961 and as such is responsible for all research and development of radar and radio equipment for the Royal Navy. He joined the Admiralty in 1938 as a young Scientific Officer and has since then played a leading part in the development of all the important radar and guided weapons systems of the Royal Navy.

RETIREMENTS

H. C. WASSELL, M.Sc., R.N.S.S.

Horace Cyril Wassell, Principal Scientific Officer, retired from the Admiralty Compass Observatory at the end of April 1967 after 27 years' service. Educated at Bishop Wadsworth's School, Salisbury and University College, Southampton, he graduated in 1926, taking London external B.Sc. in Physics and Mathematics.

In his pre-Service days he spent four years in the Persian oifields working on the applications of physics to prospecting on behalf of the Anglo Persian Oil Co., before returning to Southampton to lecture and to carry out research on heat transfer problems, which led to the award of his M.Sc. degree. In his final industrial post he spent five years on work associated with heat transfer at the laboratories of the G.E.C. at Wembley.

In 1939 Wassell was appointed temporary E.O. in the Admiralty Technical Pool and posted to A.C.O. He spent most of the war years working on anti-degaussing correction equipment for magnetic compasses, latterly being in charge of the project. With the formation of the R.N.S.S. he was established as an S.E.O., being promoted to P.S.O in 1949.

In the immediate post-war era at A.C.O., everybody was either " magnetic " or " gyro "—even the top brass one suspected—and never the twain did meet if they could avoid it. Having realised the synonymity between the magnetic compass and the dodo, Wassell was transferred from the grottoes of Gauss to lead the followers of Foucault; and for over ten years he presided with avuncular beneficence over gyro compass R & D, which also embraced stabilising gyros for magnetic compasses and artificial horizon periscope sextants.

The biggest task accomplished by Wassell and his team was the development of the A.P.5005 series gyro compass, which has kept the Navy going for more than ten years, well over 100 having been fitted at a total cost estimated at over £1m. The post-war requirements of the Navy, when more sophisticated weapon systems in general, and particularly gunnery ones, were being developed, led to demands for more numerous and more accurate compass transmissions. Whereas navigators were perhaps satisfied with 10-minute M type, gunners were asking for smooth self-synchronous indications of the true bearings. It was therefore decided, that rather than develop an entirely new compass system, the basic and well-proven master unit would be modified to comply with new requirements. Among the then contemporary innovations introduced into the compass were miniaturised AC servos for the phantom follow-up and other systems; a coarse and fine magslip combination to take compass course from master gyro to bulkhead mounted Master Transmission Unit, with computation and automatic addition of the speed error, $\delta = \frac{\text{V Cos Course}}{\text{Cos Lat.}}$ within the MTU. True course within the MTU. True course outputs were provided by a multiplicity of self-synchronous magslip, 2-minute and 10-minute M transmissions; where necessary by an additional retransmission unit. Wassell also was principal author of the BR 8, the handbook covering both the theoretical and practical aspects of the operation of the AP.5005 series.

A happy rapprochement in the magnetic/gyro rivalry was finally secured with Wassell and the late Alfred Hine as the chief protagonists. Systems of both types were to co-exist in ships at the ends of change over switch connections, allowing the naval user to be final arbiter.

With the A.C.O. being re-orientated to undertake the development of SINS, Mr. Wassell took charge of the preliminary work for a short period, but with the enormous increase in the R & D budget and the consequent expansion of work, he took over the more-than-full-time task of handling finances as well as the planning liaison with M.P.B.W. for the new A.C.O. laboratory buildings and associated facilities.

At a farewell drink-in, many colleagues at A.C.O. gathered to express their good wishes, when the Director, Capt. T. D. Ross, spoke of the universal regret felt at Mr. Wassell's departure and on behalf of all staff made a presentation of a cheque and a do-your-own A and A machine tool. Mr. H. J. Elwertowski, Chief Scientist, then made an appraisal of Mr. Wassell's contributions to the Service in general and the Observatory in particular.

Horace Wassell's many friends at A.C.O. and elsewhere will wish him and Mrs. Wassell a long and happy retirement. In Sussex-by-the-Sea, where they hope to reside near to members of their family, Horace will have scope for his interests as a naturalist, greater leisure for cultural activities and will doubtless apply his energies to pursuits of his own choosing in the same effective manner in which he carried out his duties in the Naval Service.

MISS R. M. SPRAGUE, A.L.A., R.N.S.S.

Miss Rhoda M. Sprague, Senior Assistant (Scientific) retired on 30th April after 26 years with the Admiralty, in and out of uniform. Previous to this she had been employed in the Public Library Service in South Wales, during which time she qualified as an Associate of the Library Association.

In 1941 she joined the W.R.N.S., and was drafted into the Torpedo Branch and trained in H.M.S. *Vernon's* wartime extension at Roedean School. After serving for four years on electrical maintenance duties she was demobilised in 1945 as a Petty Officer and joined Admiralty Compass Observatory, Slough, as a Laboratory Assistant where she worked on the development of the Admiralty Transmitting Magnetic Compass.

In March 1950, Rhoda transferred to H.M.U.D.E. Portland, and was at first attached to the Transducer Calibration Section, where she put in a further spell of "sea time" on the tenders. Since then, moves within U.D.E.—first to the Sound Range and then to the Minehunting Asdic section—kept her on technical work of a practical nature until, in November 1958, advantage was taken of her library training and she was moved to fill a vacancy on the library staff. This was to prove her last change of occupation, as she remained with the library until retirement—first in H.M.U.D.E. and in the combined establishment after A.U.W.E. was formed in 1960.

Miss Sprague is also well-known outside the Establishment for her work with the Girl Guide movement, in which she is the Commissioner for the South Dorset Division.

Her plans for retirement include a world tour, which she hopes to begin next October, and the parting gift from her colleagues at A.U.W.E. took the form of a cheque to help defray her travel expenses; it was presented at a small ceremony on Friday, 28th April, by Mr. W. K. Grimley, O.B.E., Deputy Chief Scientist, A.U.W.E.

OBITUARY

J. C. KINGCOME, B.Sc., F.R.I.C.

His colleagues at Central Dockyard Laboratory and his many friends were deeply shocked by the news of the sudden death of John Kingcome which occurred on May 6th at the comparatively early age of 54.

John Kingcome was educated at Farnham Grammar School, Surrey and King's College, London University from where he graduated in 1933 with an Honours B.Sc. in Chemistry. He joined the then Admiralty Chemical Department, Portsmouth as a Temporary Assistant Analyst in 1934 and became a Temporary Assistant Grade III in 1935. He was promoted Acting Chemist in 1942 and in 1943 was transferred to the Naval Construction Department, Bath as Chemist and Paint Technologist. In 1946 he was assimilated into the Experimental Officer grade and promoted to Senior Experimental Officer in 1947. During his time at Bath he established contacts with the paint industry and carried out liaison with them and the service laboratories in the period when the Navy was changing over from the use of oil bound paints to synthetic resin based materials. Following his term of duty at Bath he was transferred to the Central Metallurgical Laboratory at Emsworth where he worked on the problems of underwater corrosion and fouling. In 1957 he was transferred to C.D.L. after the closure of C.M.L. and continued his interest in underwater problems. He was promoted to Chief Experimental Officer in 1962 and from that time until his death was in charge of the section dealing with approval and inspection of paints for Naval use, together with short term investigational work and exposure and testing of these materials.

He served on many Navy Department, Inter-Service, British Standard and other committees and was the secretary of the Underwater Sub-Committee (formerly the

Antifouling Research Sub-Committee) of the Navy Department Committee for the Prevention of Corrosion and Fouling. He wrote a number of articles for technical journals and established a reputation for himself in the field of marine paints both within the Services and the paint industry.

He lived on Hayling Island and was a lay warden at St. Mary's Church. His other interests included sport, particularly cricket, and photography. At the time of his death he was chairman of the Southern Branch of the Oil and Colour Chemists Association and he had always taken a great interest in this body. John Kingcome was friendly by nature and good company and was well liked and respected by all who knew him. He leaves a widow and two daughters to whom our sympathy goes out in their great loss.

CORRESPONDENCE

To the Editor,
Journal of the Royal Naval Scientific Service
Sir,

ISOTROPIC DIRECTIONAL TRANSPONDER BEACON

J.R.N.S.S. **22,** 2 (March 1967), 61-66

The basic idea in this paper occurred to me in, I believe, 1961, and I described it then to a number of colleagues at A.S.W.E., S.E.R.L. and elsewhere. I extended, generalised and elaborated it and wrote it up as a formal article rather over a year ago and discussed this with my colleagues at A.U.W.E.

I am now indebted to Dr. D. E. N. Davies of Birmingham University for pointing out to me that I was anticipated in the basic idea, in its application to a regular linear array, by Dr. van Atta in the U.S.A. in 1956, and that its extension to a circular array and a number of variants to the basic principles have been covered by himself and his colleagues at Birmingham in work under way there since 1962. Dr. Davies' own paper in *Proc. I.E.E.*, **110**, No. 3 and the references given there are particularly pertinent.

I can only hope that the further generalisations in my paper may have helped some readers in elucidating some additional facets of the problem, or have been of value to those who, like myself and my colleagues, appear not to have been acquainted with the prior work along similar lines. Personally I am, of course, delighted to find myself in such distinguished company.

Yours faithfully,
R. Benjamin
Admiralty Underwater Weapons Establishment

To the Editor,
Journal of the Royal Naval Scientific Service
Sir,

THE CLOCK PARADOX

Bitter experience warns me that a discussion of the so-called Clock Paradox of Relativity with those who have got thoroughly entangled in it is as unprofitable as a discussion of the Second Law of Thermodynamics with the inventor of a perpetual motion machine; nevertheless, I feel that I must make some effort to blow away the fog generated by Mr. Williams in his article "A Lapse of Time," *J.R.N.S.S.*, **22,** 2 (March 1967), 67-82. The more mathematics that is put into this discussion, the more confused we shall all get; so I will cut the mathematics to a minimum.

Let me first make it celar that I propose to make no attempt to state evidence in favour of Special Relativity, nor even to explain why I feel it to be *a priori* at least as acceptable as Galilean/Newtonian theory: I shall merely try to explain what the theory states. This is surely reasonable: what is the point of debating the evidence if we disagree radically on what the theory says? All subsequent statements, then, refer to the world described by Special Relativity, without prejudice to the question of whether this is the real world or not. The basis of Special Relativity is this:

> Measurements of time and space are not independent, as Newtonian theory supposes, but linked in the same way as the three dimensions of space are with each other. . . . (1)

This is more than an analogy: it is a formal identity, except that signs have to be changed in certain places. (The relationship is exactly that between hyperbolic and circular functions, which will be familiar to most readers). If anyone objects to (1), I can only say I'm sorry, but we must be talking about different theories. I sympathise with anyone who has been trying to understand Special Relativity without accepting (1); it just can't be done. The formal statement of (1) is:

All physically significant features of space-time can be described in terms of *interval,* an element of which is defined as

$$ds = \sqrt{dt^2 - dx^2 - dy^2 - dz^2}$$

This is analogous to *distance* in geometrical space, defined by

$$ds = \sqrt{dx^2 + dy^2 + dz^2} \quad . . . (2)$$

(Real 'intervals' are time-intervals as measured by any form of clock). The whole theory can be derived from (2) (see for example Eddington's excellent treatment in *The Mathematical Theory of Relativity*, 2nd Edn., 1924), and indeed this seems to me by far the most satisfactory method of development.

(1) implies that most statements about space and time can be paralleled by statements about space alone (usually in fact by statements about plane geometry), and working out such parallels will, I believe, clear up all difficulties in understanding the theory. The 'Clock Paradox' is the following statement:

> If A, B, C are three events, such that observers can move uniformly from A to B, B to C, and A to C, and if the last observer does not pass through B, then the sum of the time-intervals recorded by the first two will be less than that recorded by the third . . . (3)

The corresponding spatial statement is the unexceptionable Triangle Axiom:

> If A, B, C are three points and B is not on the straight line from A to C, then AB + BC > AC. . . . (4)

We get 'greater' in (4) and 'less' in (3) because of the change of sign already mentioned; the same change, more subtly, necessitates the 'such that' clause in (3) which is not required in (4).

Now, as I cannot see anything paradoxical about (4), which is virtually the same statement as (3), I find myself unable to 'explain the paradox'; however, the parallel provides an explain-it-yourself kit for anyone who is worried by (3). State your difficulty, translate it into spatial terms, explain it there, and translate your explanation back into space-time. This process shows some common remarks to be more or less inaccurate; for instance that the time-difference must be 'because of the acceleration which occurs at B', or that 'Special Relativity does not allow for accelerated motion'. The former translates into 'AB + BC > AC because there

is an angle at **B**', which I suppose makes sense of a sort, but which strikes me as an unilluminating point of view; the latter into 'plane geometry does not allow for angles or curves', which is simply not true.

A common objection is that some principle of symmetry is violated by (3). The principle is usually not clearly stated, but it is presumably the one that says all 'inertial frames of reference' are equally valid (equivalent to (2), since inertial frames are those in which ds has this form); this translates into the statement that the properties of a geometrical figure are unaltered by rotation. This is not in any way in conflict with (4), and the other is not in conflict with (3).

A great deal of the confusion is caused by the regrettable statement (I do not blame Mr. Williams for repeating it, as it can be found in many reputable books) that 'a moving clock runs (or appears to run) slow'. This is the same as saying that a tilted measuring rod shrinks (or appears to shrink). Perhaps this is arguable. We set up a vertical measuring rod, and find that a man is six feet high; then we tilt the rod at say 30° to the vertical, and find that he now appears to be almost seven feet high. (The change of sign is again in evidence here). I would not dispute the right of anybody to say that the measuring-rod must have shrunk; but it again appears to me to be a singularly unilluminating point of view. I much prefer to say that the shortest distance from a point to a line is given by the perpendicular, and any oblique line is longer; and so I prefer to say that the longest time-interval from an event to a hyperplane (I should say a space-like hyperplane) is that along a line perpendicular to the hyperplane—*i.e.*, along a line representing a point which is stationary in a reference-frame in which the hyperplane takes the form t=constant—, and that the time-interval along any other line is shorter.

The historical origin of the nonsense about moving clocks running slow is, I think, that it was first said in comparing the picture given by Special Relativity with that of Newtonian theory; a moving clock behaving as Special Relativity postulates will run slow compared to a Newtonian clock. But anyone who believed in Special Relativity would be more sensible to say that the Newtonian clock runs fast. Personally, I find it rather confusing to think about two incompatible theories simultaneously.

Another source of confusion is the common overemphasis on the 'constancy of the velocity of light'. (2) implies that a 'constant' velocity exists: it is represented by a line along which ds=O, which is a physically meaningful equation, and therefore valid in every inertial frame of reference; and experimental evidence that the velocity of light has this property would be of importance if I were going to discuss the validity of Special Relativity in the real world. Further, it is interesting that we can derive the theory alternatively by starting from the assumption of the constancy of the velocity of light; but to insist on carrying out all constructions by means of 'light-signals' is rather like developing Euclidean geometry by the use of compasses only (with no straight-edge)—very entertaining if you like that kind of thing, and not without some deeper significance, but by no means the best introduction to the subject. As usual Eddington's *The Mathematical Theory of Relativity* (second edition), Cambridge, 1924 (I cite the second edition as its Supplementary Note 1, page 241, gives a good short discussion of the 'paradox'), puts this matter in the right perspective.

I must admit that our analogy (1) rather lets us down in visualising how this constant velocity arises. The corresponding thing should be directions in the plane which are unchanged by rotation, which do not exist. This is another of the more subtle effects of the change of sign: such directions would be lines with gradient $\pm\sqrt{-1}$. Anyone who has done a little projective geometry will recognize them as lines through the 'circular points at infinity' in the *complex* Euclidean plane.

Yours faithfully,

G. H. Toulmin, M.A., Ph.D.

Government Communication Headquarters

To the Editor,
Journal of the Royal Naval Scientific Service
Sir,

In a brief reply to Dr. Toulmin I make the following points:

(a) Of all the accounts known to me in English of the mathematical theory of relativity, I like Eddington's best; but I fear that something is wrong with the physical foundations.

(b) The historical origin of the nonsense about moving clocks running slow is, in my belief, attributable to Einstein 'On the Electrodynamics of Moving Bodies' who, in the translation reprinted by Dover, says: 'we conclude that a balance-clock at the equator must go more slowly, by a very small amount, than a precisely similar clock situated at one of the poles under otherwise identical conditions'.

(c) Now that an elaborate mathematical structure has been built on Einstein's foundations, it is not fair to play down the constancy of velocity of light and thus to ignore the historical development of the Special Theory out of attempts to explain the null-result of the Michelson-Morley experiment.

(d) My insistence on measuring time and distance by electro-magnetic signals is a strong one, as this is the only means I can visualize for conducting experiments by two observers in relative motion, separated by empty space from the events which they observe.

I have fired my pistol and am sorry if it has generated only fog, but I am now compressing the air for a second shot, which you, Sir, should soon hear in Kent.

Yours faithfully,

Anthony E. Williams

Admiralty Underwater Weapons Establishment

Notes and News

Admiralty Materials Laboratory

The Minister of Defence for the Royal Navy (Equipment), Mr. Roy Mason, M.P., accompanied by his Personal Assistant, Mr. John Peters, visited A.M.L. on Tuesday, 11th April. He was introduced to key members of the staff and shown selected aspects of the research programme.

Mr. A. W. Ross, D.N.P.R., accompanied by Mr. N. L. Parr, D.M.R.(N), paid a detailed visit to A.M.L. on Thursday and Friday, 16th and 17th March.

A party of local Ministry of Labour Officers visited A.M.L. on the afternoon of Thursday, 16th March, and were shown examples of the work of the laboratories and workshops, emphasis being given to the problem of recruitment of industrial workers.

A party of U.K.A.E.A. scientific and technical staff attending the Bournemouth "Diffraction Analysis Conference" on Wednesday, 3rd May, visited A.M.L. during the afternoon and were shown some of the methods employed in tackling materials research problems.

Mr. G. N. S. Farrand visited the U.S. from 16th April to 7th May, 1967, to attend a symposium on coated fabrics organised by the U.S. Army Engineer R. & D. Laboratories at Fort Belvoir, and to attend meetings of T.T.C.P. Sub-Group P, W.P.3, held at the Naval Ordnance Test Station, China Lake. He also visited various organisations concerned with the development and application of polymeric materials.

A paper entitled "A Consideration of the Possible Use of Refractory Ceramic Materials for Advanced Combustion Chamber Design" was presented by D. J. Godfrey and N. L. Parr at the Cranfield International Symposium on Combustion in Advanced Gas Turbine Systems, 4th to 6th April, 1967.

Mr. E. Carrington, Disestablished E.O., retired at the age of 70 on 24th March after 24 years' service. His colleagues marked the occasion by presenting him with a photographic electronic flash gun and gadget bag.

Mr. C. W. Platten, who had been a member of A.M.L. staff since June, 1963, died as a result of a road accident on 3rd February, 1967. Colin Platten was born in Hull and educated at Kingston High School and University of Leeds, where he graduated in chemistry in 1957. After a period of A.W.R.E., Aldermaston and with B.T.R. Industries Limited, he joined A.M.L. as a Senior Scientific Officer and had been working on the development of glass-reinforced plastics for naval application. Always a keen motorcyclist, he was on his way to visit his sister in Tonbridge when he was involved in an accident with an articulated truck on the outskirts of Winchester and died on his way to hospital. Mr. Platten was unmarried.

Central Dockyard Laboratory

Dr. C. D. Lawrence, Superintending Scientist, attending a meeting in Paris on 20th and 21st April, 1967, of the International Committee for Research on the Preservation of materials in the Marine Environment. This committee is continuing the programme of research work previously co-ordinated by the scientific branch of the Organisation for Economic Co-operation and Development.

The Controller of the Navy, Vice Admiral H. R. Law, K.C.B., visited the Central Dockyard Laboratory on 23rd March, 1967. Although, primarily, problems concerning weatherdeck-painting were discussed, the opportunity was also taken by the Controller to visit other sections of the laboratory and to meet members of the staff.

Services Electronics Research Laboratory

On the 8th March Mr. C. H. Gooch visited the University of Berne to study work on semiconductor lasers. This work is being directed by Mr. R. F. Broom who is on a year's leave of absence from S.E.R.L.

Mr. M. Hillier visited Rome on 13th March, 1967 to attend a Symposium on Residual Gases in Electron Tubes. He also visited Tarbes, France, for technical discussions on electron tube materials.

Mr. R. Bottomley attended a conference on "New Developments in Optics and their Applications" at Eastbourne 10th-12th April, 1967, whilst Mr. C. H. Gooch and Mr. K. G. Hambleton visited Bad Nauheim, Germany to attend a conference on "Semiconductor Device Research" on 19th of that month.

Mr. J. Pollard attended the International Standards Organisation meeting on Vacuum Technology in Paris from 22nd to 26th May. He went as leader of the British delegation to the Working Group on Vacuum Gauge Calibration and as a member of the delegation to the plenary sessions.

Mr. P. D. Lomer, Mr. L. N. Large and Mr. R. J. Sherwell attended a conference on "Applications of ion beam techniques to semiconductor technology" at Grenoble, France on 24th-26th May, 1967. The following papers were read at the conference: "Electrically active doping profiles produced in silicon by ion bombardment" by L. N. Large, H. Hill, M. Ball, "Semiconductor devices made by ion implantation" by L. N. Large (S.E.R.L.) and J. Kerr (A.S.M.); "Avalanche multiplication in photosensitive junctions formed by ion implantation" by R. J. Sherwell, J. Raines, L. N. Large.

S.E.R.L. at the Physics Exhibition 1967

The Physics Exhibition organised by the Institute of Physics and the Physical Society was again held at Alexandra Palace this year on 17 - 20 April. The S.E.R.L. exhibits formed part of a larger Ministry of Defence (Navy Department) stand. There were three S.E.R.L. exhibits covering the fields of lasers, microwave valves and Gunn effect solid-state oscillators. A more detailed description of these follows.

A 1 watt Argon Ion Laser

This exhibit demonstrated the first argon laser to be made in this country with a continuous output of more than one watt of visible light. Several wavelengths in the blue-green region of the spectrum can be obtained with this laser either simultaneously or individually by selec-

tion. This is achieved by the use of an intra-cavity prism to disperse the various wavelengths. Adjustment of the adjacent mirror permits laser action at one selected wavelength. In the demonstration this mirror was scanned with a motor drive to provide automatic sequential display of six wavelengths from 4727 Å to 5143 Å.

This argon laser has been developed at S.E.R.L. during the past year to meet a need for a high power visible output laser. Further models now under development will employ different materials and methods of construction to provide a much more compact device. The laser has been used at S.E.R.L. for investigation into "holographic" techniques and applications. A number of these lasers are also being supplied to other Government laboratories; the laser is therefore designed to be semi-portable and is not connected to a vacuum pumping system. It operates with an argon gas pressure of a few tenths of a torr and a reservoir of this gas is attached to the laser through a tap. The only regular attention required is occasional topping up of the laser gas pressure to replace losses due to ion bombardment.

The argon laser is particularly suited to holography because of its intense output in a region of the spectrum where photographic emulsions are most sensitive.

The demonstration in this part of the exhibit showed how multiple hologram records of three-dimensional objects can be stored on one photographic plate and subsequently viewed independently. The laser is used as the coherent light source needed to make the exposures, the angle of the photographic plate being changed by a few degrees between each exposure. The reconstruction of such a hologram record was shown in the exhibit using a filtered mercury lamp as a monochromatic light source, and by rotating the plate through the appropriate angles in the light beam this enabled the viewer to see a sequenced display of four originally separate objects.

A 1 kW CW Travelling Wave Tube for the 5 - 10 GHz Band

This was an exhibit illustrating new technological advances in the field of high power microwave travelling wave tube amplifiers. The valve on display was a helix travelling wave tube with an instantaneous bandwidth of an octave from 5 - 10 GHz, and a maximum CW power output of 1 kW. This rather spectacular performance has been made possible by the use of beryllia ceramic supports for the helix.

Of the many slow wave circuits which have been used in travelling wave tubes the simple helix still offers the most attractive electrical properties, particularly in respect of its very wide bandwidth. Helices, however, have always been severely limited in mean power handling capability because of their poor heat dissipation. Until now, helix circuits have usually been cooled by radiation or by conduction through alumina ceramic supports, neither of which is very effective. In order to achieve a mean or CW power output much above 100 watts at microwave frequencies it has therefore been necessary to use a more massive slow wave structure, and accept its restricted bandwidth.

This situation has been radically changed by the development of the technology of beryllia ceramic, which combines an exceptionally high thermal conductivity with excellent electrical insulation and a moderate dielectric constant. It is now possible to make good thermal connection to helices and similar slow wave structures with little modification of their electrical properties.

The 1 kW CW output of this helix TWT is about an order of magnitude greater than can be obtained from an octave-bandwidth tube by conventional methods.

An Analogue of the Gunn Effect Microwave Oscillator

This analogue was designed to give insight and understanding into the working of Gunn effect oscillators. These are devices which generate microwave power by the application of a voltage across a very small crystal of the semiconductor Gallium Arsenide. The apparent simplicity of the device however covers a rather complex behaviour, the details of which are still not completely understood. The analogue was intended to help in understanding these details and it has already been successful in a number of directions.

A more detailed description of the operation of Gunn effect oscillators has already appeared in *J.R.N.S.S.*, **22**, 2 (March 1967).

⚓ ⚓ ⚓

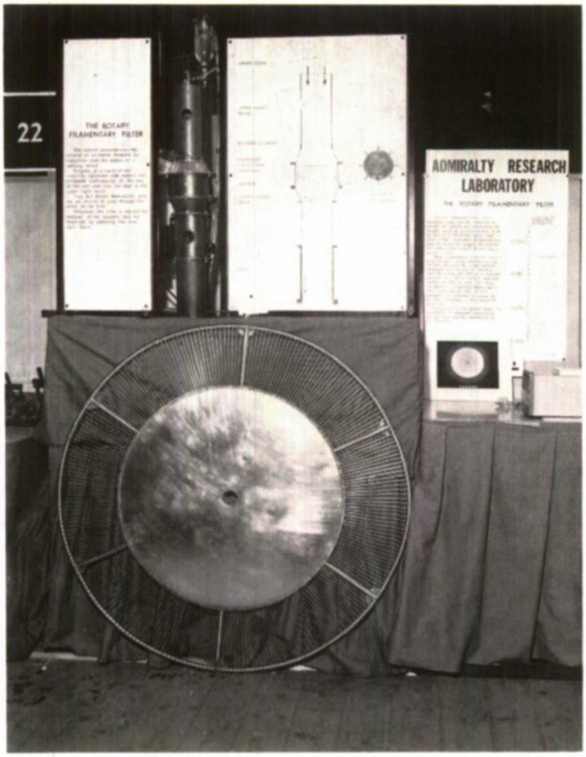
Admiralty Research Laboratory

Although A.R.L. did not contribute this year to the M.O.D. (Navy) display at the Physics Exhibition, at the request of the National Research and Development Corporation, an exhibit of the A.R.L. filters was the central feature of their stand.

The A.R.L. Rotary Filamentary Filter is an entirely new concept in gaseous filtration and has the following advantage: it is self-cleaning, is compact, has a low pressure drop, has a virtually unlimited through-put and requires negligible maintenance.

The essential feature of the filter is the rotating brush. This consists of a central disc, an outer rim and a number of radial wires or filaments stretched between them. The brush is placed in the cylindrical gas (air) duct and rotated, usually by an electric motor. Gas born particles will impact upon, rather than flow round, an obstacle at sufficient high value of Stokes number. In this device the obstacles are constituted by the filaments and the high Stoke number is obtained by rapid rotation of the brush.

Droplets impacting on the filaments adhere and are centrifuged to the outer rim where they are collected by a stationary outer collecting surface which may be continually washed. Solid particles behave similarly when the filter is 'lubricated' by a very small quantity of a suitable liquid fed to the central disc.



The efficiency of filtration for a given particle size is a function of many inter-related design parameters, of which the following are the most important:—

1. Overall diameter,
2. rate of rotation,
3. number of filaments,
4. length of filament,
5. diameter of filament.

Broadly speaking, however, the efficiency can be designed to be virtually 100% for a particle size above 5 micrometres, and below 2 micrometres it tends to fall off rapidly.

The principal parameters of the demonstration model were as follows:—

effective outer radius—6·5 cm
filaments—184 33 s.w.g. brass wires each 1·4 cm long
speed of rotation—1840 rev/min
air flow—15 ft^3/min
efficiency—virtually 100% down to 7 micrometers.

The large experimental brush also shown had the following parameters:—

effective outer radius—1 ft 10 in.
filaments—252 14 s.w.g. brass wires each 18·9 cm long
speed of rotation—1,000 rev/min
air flow—10,000 ft^3min
efficiency—virtually 100% down to 10 micrometres.

⚓ ⚓ ⚓

University and Royal Naval Collaboration in Scientific Research

As part of the Government's Policy to improve the co-ordination of the Scientific effort of the country and to make full use of the technology and expertise available within the Defence Research Establishments, a link has been forged between the University of Southampton and the Admiralty Surface Weapons Establishment.

It is planned that Senior Staff of the University will play an increasing part in the research activities of the Establishment and that the Naval Scientists will participate in the teaching and research of the University.

Common research projects are planned to be undertaken either at the University or within the Establishment which will be recognised for the purposes of Higher Degrees.

⚓ ⚓ ⚓

Launch of New Leander Class Frigate

H.M.S. *Hermione*, a Leander Class frigate, was launched at the yard of A. Stephen & Sons Ltd., Linthouse, Glasgow, on Wednesday, April 26th.

The ship was named by Mrs. Mallalieu, wife of Mr. J. P. W. Mallalieu, M.P., the former Minister of Defence for the Royal Navy, and the religious ceremony conducted by Mr. E. Wood, Minister of Linthouse Church.

H.M.S. *Hermione* which has a standard displacement of about 2,000 tons, an overall length of 372 feet and a beam of 43 feet will be powered by steam turbine machinery supplied by A. Stephen & Sons Ltd., with gearing by David Brown Industries Ltd.

Her armament will consist of 4·5 inch guns in a twin mounting directed by a fully automatic radar controlled fire control and gun direction system, a *Seacat* ship-to-air launcher and director, and an anti-submarine mortar. She will also carry a helicopter for anti-submarine use. She will have a bridge structure giving all round visibility and the operations room information will be handled and presented using semi-automatic techniques.

As with other ships of the class, a high standard of living accommodation has been achieved for the ship's complement of 17 officers and 246 ratings. This includes bunk sleeping, separate dining halls and cafeteria messing. Modern electric galleys are being installed and the ship will be air-conditioned throughout the operational spaces and messdecks.

⚓ ⚓ ⚓

Naval Fluidics

A demonstration of fluidics was a feature of the Royal Navy stand at the London International Engineering and Marine Exhibition, held at Olympia and Earls Court, from April 25th to May 4th, 1967.

Although the wall-attachment or Coanda effect has been known for about forty years, its application to fluid logic devices is comparatively recent. Considerable impetus to the development of fluidics was given by one U.S. Space Programme but, so far as is known, the applications in this country have been few—particularly in marine engineering.

A working model showing part of an automatic starting and protection system was demonstrated using wall attachment devices.

The design and manufacture of a prototype system has been made in collaboration with the Plessey Company and is being evaluated in the laboratory, but although the exhibit showed only a small part of the completed system, it did demonstrate effectively how a visual and audible alarm could be instigated from pressure, temperature and liquid level sensors.

For the exhibit the logic circuit used two types of fluid logic elements, the bi-stable amplifier and OR/NOR gate. The bi-stable amplifier or flip-flop was one of the first devices to be developed in fluidics, and its operation is such that the power stream will attach to one or other wall of the diffuser by the "Coanda" effect remaining there until a small pulse through the appropriate control port causes the power stream to flip to the other side.

The OR/NOR gate works on the same principle as the bi-stable amplifier, but, if neither control port is energised the power stream issues from the NOR output port on

the right. If either control port is energised the power stream issues from the OR output port on the left.

A logic circuit for a single sensor and Klaxon alarm was shown. With the system operating in the "NO FAULT" condition there is a control signal giving an OR output. When a fault occurs, the control signal ceases and switches over to the NOR output which is fed to the Klaxon amplifier circuit, so setting off the audible alarm at the same time a signal is fed to the indicator.

Pressing the reset button stops the Klaxon by sending a control signal to a second element which flips over to the OR output. After the fault is rectified the indicator can be reset by pressing the indicator reset button.

Book Reviews

Fundamental Atomic Physics. By D. H. Tomlin. Pp. x + 658 + 9 plates. London: Blackie & Son Ltd., 1966. Price 85s.

The latest book in the 'Student's Physics' series of textbooks for Honours degree students, this book, in a clear and original format of three sections, presents the most important fundamental concepts in Atomic Physics.

The first section is a historically based account of the experiments, and the deductions to be drawn from them, that led to the formulation of classical atomic theory. Descriptions of the original experiments, in just sufficient detail, stimulates the reader's interest and confidence and are followed by an outline of more recent measurements to illustrate how the inaccuracies are minimised. Where necessary, modern theoretical explanations have been introduced at an early stage to explain classical anomalies.

The recapitulation of classical atomic physics is completed in the second section, which develops certain selected topics, ranging from classical mechanics, waves, and electromagnetism, to the special theory of relativity. Thereby Dr. Tomlin has ensured that, in establishing the basic principles, the student has received an adequate grounding in classical atomic physics and, incidentally, help in exercising the mathematical tools necessary for the appreciation of the full quantum mechanical treatment in Section III. This last section is devoted to an exposition of the fundamentals of the quantum mechanical model of the atom, suitable for third year undergraduates and for post-graduates of other disciplines as a basis from which to assimilate more advanced and specialised texts.

Appreciating, from the wealth of his experience, the difficulties encountered by students, the author has developed his subject emphasising the Bohr Correspondence Principle of atomic and macroscopic physics throughout the initial sections. In Section III, it follows naturally that he should show that the macroscopic observations of the previous sections are merely a particular case in the quantum mechanical model. Over 240 illustrations and tables within the text amplify the salient points in the development of the theory, and references within the text avoid tiresome interruptions to look up lists of references. Likewise he has included 24 selected examples, set in an appendix, which develop some of the previous deductions and at the same time exercise the reader's mathematics. In the text only the outline of the mathematical approach is given, it being assumed that the reader is equipped with an adequate knowledge of the techniques necessary.

Without resorting to elaborate artifices, this book is neat in presentation and maintains a strictly academic approach to the subject. It comes into the class of text book that one retains as a reference volume to which one may resort for a quick revision of the basic principles before plunging into more specialised advanced texts.

P. R. Parkman

The Elastic Analysis of Flat Grillages. By J. Clarkson. Pp. vii + 132. London: Cambridge University Press. 1965. Price 52s. 6d.

At first sight it would seem that with the advent of electronic digital computers, the book is out of date. The reviewer believes this would be an unfair criticism because we are still a very long way off the day, if it ever comes, when unlimited computational facilities will be generally available and easily used. Furthermore, many local organisations which have their own computers will prefer to write their own grillage programs which place particular emphasis on features special to their needs. There appears to be therefore a two-fold requirement in a book on this topic. For those potential users who do not have ready access to a suitable computer, the basic equations of grillage analysis should be presented, with their solution by approximate methods, designed to reduce the arithmetic, together with graphs or tables providing the results of a systematic series of calculations for bending moments and deflections for a wide variety of practical configurations of load and structure. These prove useful, not only in the routine design of grillage structures, but in the optimisation of such structures as well. Where computers are readily available, potential users will want a book which presents the basic theory and discusses possible computer solutions, as several differing approaches to this problem exist.

With minor reservations the reviewer believes Mr. Clarkson's book meets both of these needs admirably. He is an accepted authority on the subject, and has produced a book which tackles in his deceptively simple, yet penetrating way, this specialised topic. It is expertly condensed, very readable, and most newcomers to the subject would find it easy to understand and use. Furthermore, the book actually goes a little further than suggested by the word "analysis" in its title in that design philosophy appears here and there, particularly in the chapter dealing with minimum weight design. The emphasis throughout is on singly plated grillages, as commonly exist in Ship Structures.

The Introduction is briefly historical (but omits the early Russian work by Boobnov extended by Papkovitch), and makes a plausible case for the elastic design of plated grillages, as distinct from plastic design. The complexity of the problem is discussed and simplifying assumptions clearly stated. The basic theory of the Force method of solution is presented in Chapter 2, and symmetrical and anti-symmetrical flexibility coefficients are used for numerical convenience. Unfortunately, these are presented only for the classic cases of clamped or pinned edges, but the corresponding equations for any general rotational edge constraint are easily derivable.

Chapter 3 presents three approximate methods of solution, emphasis throughout being placed on the special convenience of each method and the order of

accuracy which may be expected. An example of each method is outlined. The author provides a useful discussion of the use of Bernoulli's numbers Bn, to speed up convergence in the orthotropic plate theory and avoids the vexed question of deciding what rigidity to use in the torsion term hy sensibly ignoring it for open section stiffeners.

Chapter 4 is devoted to the exact and mathematically elegant Fourier series method, which considerably reduces numerical labour by arranging for p independent sets of q simultaneous equations (p and q are the number of stiffeners in each orthogonal set) rather than pq equations by the Force method. Another exact and perfectly general method which might usefully have been presented by the author is the Laplace transform technique which also reduces coupled systems of ordinary differential equations to systems of algebraic equations, very suitable for solution by electronic digital computer. The displacement method is developed in matrix form for computer solution in Chapter 5, in sufficient detail to see the logic and input and output requirements for use with any computer (the program was written for PEGASUS); and the next Chapter discusses admirably the effects of shear and torsion on bending moments and deflection.

Chapter 7 is devoted specifically to Ship grillages, as opposed to beam grillages more usually met in land structures. The two most important and convenient concepts introduced are effective plate, and effective load on stiffeners for grillages stiffened in one direction only and for orthogonal grillages under pressure loading. Largely because behaviour is sensitive to as-built shape imperfections, the author wisely derives empirical rules for these parameters based on experimental results from full scale structural tests. The following chapter describes the efficiency of various intersection connections for welded Tee stiffeners, but unfortunately omits reference to the requirments for the edge connections where weakness could seriously reduce load capacity.

Useful pinned edge data sheets for centrally loaded grillages are presented in Chapter 11 covering a wide range of practical grillage proportions. The next chapter is particularly instructive and useful for anyone concerned with least weight design of grillages with concentrated loads. It presents a method which makes use of the data sheets, and provides useful design advice. In plated grillages it is assumed that the plate thickness is fixed from other considerations. A similar study for uniform pressure loading has unfortunately not so far been tackled.

The last chapter is perhaps the most valuable of all, in providing an extensive range of bending moment and deflection data sheets for pressure loading on uniform grillages with opposite pairs of edges either pinned or clamped. For numerical convenience the author divides the load into equal concentrated components at the intersections, and local bending between intersections has to be considered separately where this may be significant. This causes a certain amount of inconvenience, but has the great merit that as further experimental or theoretical information becomes available concerning these effective local loadings the main data sheet hending moments will still apply. Two examples are given.

The book ends with a well selected hibliography, naturally with a Ship bias, and a brief but adequate index. The text and figures are clear and reasonably free of errors, for a first edition (the only one that isn't reasonably obvious occur in Figure 58 where the ordinate of the graph should have "a" in the denominator and not "b"). The book is very welcome, fulfils a definite need, and is confidently recommended by the reviewer as a happy blend of advanced theory and practice.

D. Faulkner

Theory of Crystal Dislocations. By A. H. Cottrell. Pp. 94. London: Blackie & Son Ltd., 1964. Price 32s. 6d.

This booklet presents the basic facts of dislocations in crystalline lattices in a simple, but concise form. Prof. Cottrell who took a large part in the early development of dislocation theory, is a past master in the art of presenting physical arguments with a minimum of mathematics. The suhstance of the text is hased, almost without change, on notes used for his 1956 lectures at the summer school at Les Houches near Grenoble, and is aimed particularly at graduate metallurgists. Short notes have been added at the end of each chapter, to descrihe very briefly the most important development in the field up to 1962.

Individual chapters deal with slip, the geometry, elastic field, forces on, and dynamics of, moving dislocations etc., whilst the last chapter briefly mentions the very wide fields of application of the theory to the properties of real (imperfect) crystalline solids. In a short reference the most important papers, prior to 1955, are listed which deal with the scattering at dislocations of phonons, photons, electrons and neutrons, and with their effects on crystal growth, diffusion, precipitation and phase transformation. The booklet will certainly be read with advantage by any student of metallurgy interested in dislocations.

E. Billig

Advances in Electronics and Electron Physics. Vol. 20. Ed. L. Marton. Pp. x + 332. London and New York: Academic Press Inc., 1965. Price 86s.

As the title implies, these volumes assume a fairly intimate familiarity on the part of the reader with the subjects under discussion which are brought up-to-date from time to time, supported by extensive bibliographies. The present volume contains three closely related articles on plasmas, two on radio-waves and one on electronic aids to the blind.

The field of plasma physics now covers an extremely wide range of phenomena and a correspondingly large range of possible practical applications; from arc-discharge tuhes to direct energy conversion and to nuclear fusion reactors. In the first of these articles, R. G. Fowler discusses the behaviour of electrons as a hydrodynamic fluid. A plot of free-electron density *versus* temperature reveals the many different conditions under which plasmas can occur in nature, from the low-temperature ionosphere to glow-discharges, arcs and stellar nuhulae at medium temperatures, $\sim 10^4$ °K, to the high-temperature, high-concentration conditions in nuclear fusion machines, and the very-high-temperature and concentration conditions in the true thermo-nuclear plasma in stars. Individual chapters of the article deal with electric shock-tubes and the different types of their "drivers". K. G. Emeleus's article deals with oscillations in plasmas, of Debye lengths smaller than the dimensions of the container. This article presents a large collection of individual phenomena rather than a unified picture of the whole field. A. von Engel's and J. R. Cozens's "Flame plasmas" on the other hand is a classic. After a brief historical introduction, combustion reactions in, and ionization of, flames are treated in turn, with discussions supported by simple order-of-magnitude calculations. Chapters on the physical properties and electrical measurements of flames conclude this very lucid account.

The two articles on "Solar Radio-Astronomy" by A. Boischot and V. F. Denisse, and on "Tropospheric propagation" by P. L. Rice and V. W. Herbstreit are complementary. The latter article in particular conveys a vivid account of the intensive research on the propagation through the atmosphere of radio waves, down

to the microwave range, and the many mechanisms of attenuation. The article concludes with a demonstration how the many factors involved in a given practical transmission system can be assessed quantitatively in the form of " service probability ".

The last article, on " Electronics and the Blind " by P. G. Schrager and C. Süsskind, takes a broad look at the many fields in which electronics can aid the blind. These are grouped under two main headings, *i.e.* guidance devices and methods of sensory stimulation. Whilst considerable progress has been made in the former field, especially due to the rapid development of solid-state devices in the last decade, much remains to be done at the " receiver " end of the system. In certain fields as *e.g.* in electronic reading devices where the tasks are much more complex than in mere guidance problems, interest has recently shifted to the psycho-neurological aspects of the problem.

This 20th volume of the "Advances" maintains the high standards to which readers have become accustomed, thanks to the continued efforts of the editor, Dr. L. Marton, who has guided his contributors so successfully to this " anniversary " volume of the series. It is a particular pleasure to the reviewer who was fortunate enough to contribute to the first " decade " issue, to congratulate the editor and wish him " many happy returns ".

E. Billig

Semiconductor Thermoelectric Devices. By A. I. Burshteyn. Pp. 131. London: Heywood-Temple Press Books Ltd., 1964. Price 35s.

This booklet, a translation from the Russian, is concerned with the problems of heatflow and electric current through two dissimilar solids connected in series, in the presence of the thermoelectric Seebeck-, Peltier-, Thomson-, and Joule-effects, and with the solution of the corresponding mathematical equations under various conditions. Some analytical solution of these complex problems is required before efficient thermoelectric devices can be constructed. Unfortunately the statement of the problems involved and their mathematical treatment are here presented in a form which makes it very hard to follow even with the best will in the world. Without any consideration for the reader, there are pages upon pages of mathematics; with no list of symbols; some of the solutions are illustrated by a few curves, but even then are without figure captions or explanatory notes; abscissae and ordinates are marked only by a symbol; quantitative values are given without their meaning, units or dimensions. In desperation the reviewer sat down to write his own list of symbols, but had to give it up in the end.

The booklet is divided into three major chapters: Thermoelectric cooling, -heating, and -generation, each treated mathematically in great detail. Yet there is no clear-cut statement of any conclusions reached, no discussion of the effect of the main parameters involved in the operation of these devices, and no Tables listing their quantitative values for the different types of solids used: metals, alloys, semiconductors.

On the whole, this is a very frustrating treatment of a subject which is both highly interesting theoretically and of great practical use potentially. The designer of thermoelectric devices will look in vain to this booklet for basic guidance in the design, or for help in the selection of appropriate materials and in the practical construction of such devices.

E. Billig

Semiconductors and Their Circuits. Vol. 1. By N. F. Moody. Pp. xxx + 345. London: English Universities Press, 1966. Price 42s.

This volume is one of a series of texts in Electrical Engineering, presenting advances in the various subjects and a detailed re-evaluation of basic principles.

This book is undoubtedly of much more value to the postgraduate research engineer or physicist than to the undergraduate or general electronics engineer. This reviewer felt that the title might well have been ammended to read " Semiconductors and their Equivalent Circuits " because a very large part of the volume is spent in considering the mathematical development of the equivalent circuit theory.

Practical transistorised circuits are not discussed or developed, the accent being entirely on the transistor as a device. Nevertheless, from the development point of view, this book is first class in providing a compact reference volume, pointing the ways ahead to various applications, and developing thoroughly the underlying theories and constraints.

Not a book for the layman or merely interested amateur. Very definitely a must for all researchers in the (sic) transistor device development field, and within those limitations good value at 42s.

R. W. Sudweeks

Topology and Matrices in the Solution of Networks. By F. E. Rogers. Pp. 204. London; Iliffe Books Ltd., 1965. Price 45s.

I am quite convinced that one of the most important aspects of educational theory ought to be the emphasis of the generality of scientific disciplines. Mr. Rogers's book left me with the feeling that I wished that I had read it years ago—how much easier life would have been!

But, a word of caution. The book provides a topological approach to Network Theory, and if the reader has been educated in the classical traditions of Norton, Thevenin, *et al.*, then he is liable to become impatient with the solutions offered. If, however, the reader has not been subjected to these treatments then Mr. Rogers offers a much more rational approach to the problem, and I think that it is in this that the book makes a large contribution to the teaching of network theory.

The book comprises five chapters, dealing with The Rudiments of Topology for Electrical Networks; Practical Procedures for the Formation and Solution of Network Equations; On Theorems, Duality and other Principles; Matrices Applied to 4-Terminal Networks and Groups of Networks; and Annotated Problems. Throughout simple and readily understandable, numerical problems are dealt with and in some cases alternative solutions are offered to provide a clearer exposition.

My background is electrical engineering, and for the past few years have been dealing with Systems Analysis and Logic Design. In the course of this latter I have been more and more impressed with the inter-discipline generalities. This book brings these generalities out in an extremely lucid fashion, dealing for instance with circuit dualities and virtually mapping solutions.

Topology and Matrices will be of interest to all students in all branches of science and engineering. It provides an invaluable source of reasoned circuit analysis theory and practice for both undergraduate and graduate alike, and should be of value to H.N.C. students also. A very nicely presented book, excellent value for 45s.

R. W. Sudweeks

Science and the Skin. By A. Jarrett. Pp. 167+18. English Universities Press Ltd. 1964. Price (paper-back) 12s. 6d.

This little book, the author states in his preface, " is written primarily for the non-medical reader. It is an attempt to explain in non-technical language the function of the skin and its associated structures." It is designed especially for " biological and non-biological scientists who are interested in the skin ", and " is not in any way intended to be a book on skin diseases for the lay public ".

One can but wonder how many " biological and non-biological scientists " there are who are interested in the skin, and fear that if this book were restricted to such groups, the profits would surely be minimal. This is a pity, as here is a remarkably sensible approach to the physiology and pathology of the skin, deserving a far wider appeal. There is much information in it that would not appear even in the standard text-books on dermatology, and could well be read with benefit by fourth year medical students upwards. The reviewer was particularly impressed with the author's stimulating views on acne.

The price is of course one of its main attractions, and any purchaser should therefore be warned that it does not contain a single photograph of any skin disease.

R. W. B. Scutt

The Dynamics of the Upper Ocean. By O. M. Phillips. Pp. vii + 261. London, Cambridge University Press, 1966. Price 60s. or $11.50.

The upper ocean referred to in the title is the top few hundred metres of the sea. It is a region in turmoil, characterised by temporary thermoclines and by a great variety of motions. It is important in its own right, and also because any interchange of energy between the atmosphere and the deep ocean must pass through this complex region. Although the elementary properties of the motions have been known for some time, it is pointed out that about a decade ago there was still almost complete ignorance on some important problems. For example, many people are aware to their sorrow that high winds produce rough seas—but how do they do it? Only in the last few years has it been recognised clearly that ripples are necessary for the process to start, the wind cannot bite on the surface and achieve full surface drag until the short waves are established.

The author sets out to summarise recent developments in the dynamics of the upper ocean, covering three major topics and their inter-relations. These topics are ocean surface waves, internal waves and turbulence. The two chapters on surface waves cover wave interactions, the generation and the attenuation of waves, the specification of a wave field and the wave spectrum, gravity waves and capillary waves. It is not surprising that this subject takes up slightly more than half the book. The chapter on internal waves has a similar scope and a similar theoretical difficulty. But this is a newer subject since waves in an interface deep in the ocean are hardly a part of everyday observation, and progress is slowed down by their remoteness to experiment. The last chapter discusses turbulence, its occurrence and characteristics. One of the best-known, but still surprising, results of turbulence is the development of a really sharp thermocline by erosion of the mixed surface layer into the underlying water. In addition, the book has introductory material, a section on the basic equations of motion, a bibliography and an index. One of the points about the book is that the collecting together of the three main topics allows full weight to be given to the many interactions. A specific example is the theoretical possibility of two surface waves, close in frequency but not in direction, producing an internal wave at the thermocline. Calculations suggest that this type of resonant coupling may be highly significant, but there are obvious difficulties in a thorough experimental check.

Thus, Professor Phillips's intention is to give a coherent account of his three subjects, and where there are gaps in theory or experiment he hopes to provide stimulation. He succeeds on both counts. The book is one of the Cambridge Monographs on Mechanics and Applied Mathematics, and is well described as a monograph (in the best sense of the word); it is not a text-book, nor for the too casual reader. It is full of " meat ", is lucidly presented, and should be invaluable to the serious student and research worker. The emphasis is on theory and the book is ordered on a theoretical structure, but the accounts of relevant experiment are both useful and interesting.

D. E. Weston

British Destroyers. By E. J. March. Pp. xxxii + 539, with 175 photographs and 100 plans. London; Seely, Service & Co. Ltd., 1966. Price 10 guineas.

As Lord Mountbatten suggests in his foreword to this book, love of a ship may be felt by every true sailor, but it is probably destroyers which have inspired the greatest affection and undying devotion among all those who served in them.

The author was invited in 1959 to write the history of British Destroyers, and acknowledges the unfailing assistance he received from the Admiralty and from the contractors. In general, each class, from the 27-knotters or 'A' Class of the 1892-3 Programme to the Darings of the 1944 programme, is allotted a chapter which includes names, builders, speed, armament, cost. Their Lordships' reactions trial results, comments from sea, hull diagrams, war service and a host of other information, including really excellent photographs. Other chapters are devoted to the early history of torpedo boats, actions in the first world war, direction finding and radar, the second world war and the development of machinery, guns and torpedoes over 50 years. In passing, the development of navigational equipment, other than radar, might well have found a place in the latter chapter, but perhaps the author felt the book was already large enough.

Looking through the details, there are so many memories which are recalled in these pages. For example, few people may still remember the personalities and background involved in *Hotspur's* trials (p.309) when she hit a rock in a fog somewhere off the Clyde. Then again, of all the scores of trials of destroyers and other ships in which your reviewer has taken part, those of *Kelly* on the Tyne were the only ones during which strawberries and cream were served for luncheon.

Other points, among many which arise, are the Admiralty's strange and somewhat draconian (not to say barbarous) methods of calling for tenders in the early days—some firms were broken by the 30-knotters. Also interesting is the use by the Admiralty, about 1894, of the term " knot " for nautical mile and also of " knots per hour " (p.45). It is also worthy of remark that H.M.S. *Ghurka* (1905-08 programme) was succeeded by H.M.S. *Gurkha* (1935 programme).

The production is excellent and the photographs, as mentioned above, superb. There is an adequate index and an inadequate list of abbreviations.

Recent years have seen the production of a number of books on naval subjects, some dealing with single ships (Richard Hough's story of H.M.S. *Agincourt* in

"The Big Battleship"), some with classes (Commander Aulden's "Flush Decks and Four Pipes" and Don Everitt's "The 'K' Boats") and some with whole types of ships (Oscar Parkes's "British Battleships"). But, other than the volume under review, none will be a more useful source of reference nor will be more effective, not only in reminding old destroyer hands of what was, after all, a way of life, but in perhaps recalling memorable days to those who may have served only fleetingly in destroyers during their service careers.

A. V. Thomas

Histochemistry of Skin—Psoriasis. By A. Jarrett and R. I. C. Spearman. Pp. ii + 115. English Universities Press Ltd. 1964. Price 25s.

This little book is described as "a monograph on normal and parakeratotic epidermal keratinisation with special reference to Psoriasis and its treatment". Enzymological and histochemical techniques (including fluorescence microscopy) were used in the study, which was carried out in the Dermatological Department of the University College Hospital Medical School.

Various accepted methods of the treatment of psoriasis are discussed, in relation to their effect on abnormal keratinisation. The most dramatic form of therapy is undoubtedly topical steroids with polythene occlusion, but this cannot be continued indefinitely, and the condition tends to relapse very quickly when the occlusive dressings are permanently removed. The authors have demonstrated, however, by experimental work on mouse-tail scale keratin, that if Vitamin A is applied with the steroid (but without occlusion), the keratinisation approaches that of normal human skin.

A clinical trial using Vitamin A in Triamcinolone ointment, tended to confirm Whittle's report (1961) that this is a useful form of treatment in some cases of psoriasis.

Whether or not this represents a major breakthrough in the control of this disease is open to doubt.

Reference: WHITTLE, C. H. *et al.* (1961). *Brit. J. Derm.*, **73**, 433.

R. W. B. Scutt

Books available for Review

Offers to review should be addressed to the Editor

Local Atomic Arrangements Studied by X-Ray Diffraction.
J. B. Cohen and J. E. Hilliard.
Gordon and Breach Science Pubrs. Inc. 1966. $22.00. (No. 1512).

Recent Developments in Particle Physics.
M. J. Moravcsik.
Gordon and Breach Science Pubrs. Inc. 1966. $15.00. (No. 1513).

Digital Computers. A Practical Approach.
J. P. Marchant and D. Pegg.
Blackie and Son Ltd. 1967. 27s. 6d. (No. 1516).

Metals Reference Book. 4th Edition. Vols. I, II and III.
C. J. Smithells.
Butterworth and Company Ltd. 1967. 315s. 0d. (3 Vols.) (No. 1519).

Germanium.
V. I. Davydov.
Gordon and Breach Science Pubrs. Inc. 1967. $18.00. (No. 1521).

The Cytology of the Protein Synthesis in Animal Cell.
Volume II.
B. V. Kedrovskii.
Gordon and Breach Science Pubrs. Inc. 1967. $29.50. (No. 1522).

Acoustics.
G. R. Jones *et al.*
English Universities Press. 1967. 10s. 6d. (No. 1523).

Microbiological Methods. 2nd Edition.
C. H. Collins.
Butterworth and Company Ltd. 1967. 62s. 0d. (No. 1524).

Statistical Methods and Formulae.
C. G. Lambe.
English Universities Press. 1967. 27s. 6d. (No. 1525).

Advanced Engineering Science for Mechanical Engineering Technicians.
C. A. Scovell.
G. Harrap and Company Ltd. 1967. 32s. 0d. (No. 1526).

The Design Method.
S. A. Gregory.
Butterworth and Company Ltd. 1966. 95s. 0d. (No. 1529).

Electricity from M.H.D. Volumes I, II and III.
Proceedings of Symposium. Salzburg, 4th to 8th July, 1966. European Nuclear Energy Agency. 1967.
Volume I 106s. 0d. Volume II 169s. 0d. Volume III 148s. 0d. (No. 1530).

Printed for Her Majesty's Stationery Office by Lightbowns Ltd., Ryde, Isle of Wight. 1578/2525/7/67

NOTICE TO READERS

The Editor extends to all readers of the JOURNAL a cordial invitation to contribute articles of R.N.S.S., Naval or general scientific and technical interest.

Authors are requested particularly to note that as the JOURNAL is in the Restricted category the printing of material within its pages does not constitute open publication and does not prejudice the subsequent use of the material in the journal of a learned Society or Institution, or in the scientific and technical press.

Manuscript should be typewritten if possible, in double spacing and on one side of the paper only. It should include, in addition to the title, the name of the author together with initials, degrees and Department, Establishment or Ship. Pseudonyms are acceptable only in special circumstances. A convenient length is between 3,000 and 5,000 words, but other lengths are acceptable and no contribution would be debarred on this ground alone.

Illustrations are in most cases a desirable addition. Photographs should be of good quality, glossy, unmounted, and preferably between two and three times the size of the required final picture. Graphs and line drawings should be made on a similar large scale, with bold lines to permit reduction in block making.

Views and opinions expressed in the JOURNAL are not necessarily endorsed either by the R.N.S.S. or by the Editor.

All communications should be addressed to:—

H. L. R. Hinkley, Editor,

Journal of the Royal Naval Scientific Service,

Ministry of Defence,

Block 'B,' Station Square House,

St. Mary Cray, Orpington, Kent.

Telephone: Orpington 32111 Ext 258

[dstl]

Information Centre
Knowledge Services
[dstl] *Porton Down,*
Salisbury
Wilts
SP4 0JQ
Tel: 01980-613753
Fax 01980-613970

Defense Technical Information Center (DTIC)
8725 John J. Kingman Road, Suit 0944
Fort Belvoir, VA 22060-6218
U.S.A.

AD#:
Date of Search: 15 February 2007

Record Summary:
Title: Journal of the Royal Naval Scientific Service
Covering dates 1967 July
Availability Open Document, Open Description, Normal Closure before FOI Act: 30 years
Note Vol 22 No 4
Held by The National Archives, Kew

This document is now available at the National Archives, Kew, Surrey, United Kingdom.

DTIC has checked the National Archives Catalogue website (http://www.nationalarchives.gov.uk) and found the document is available and releasable to the public.

Access to UK public records is governed by statute, namely the Public Records Act, 1958, and the Public Records Act, 1967.
The document has been released under the 30 year rule.
(The vast majority of records selected for permanent preservation are made available to the public when they are 30 years old. This is commonly referred to as the 30 year rule and was established by the Public Records Act of 1967).

This document may be treated as UNLIMITED.